STONE TOOLS EMPLOYED IN PREHISTORIC METAL MINING

A functional study of cobblestone tools from prehistoric metalliferous mines in England and Wales in relation to mining strategies by use-wear analysis and cobble morphometry

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submitted for the degree
of Doctor of Philosophy

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1995

The original thesis contained three, 3.5 inch diskettes. These have been copied as additional content.

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KEYWORDS: Prehistoric, Britain, Stone Tools, Metal Mining, Function, Use-wear, Cobble Morphology

ABSTRACT

This is a study of cobblestone tools from metalliferous mine sites in England and Wales dated to the Bronze Age which were most probably used to extract copper ore. The site assemblages studied are from the Great Orme, Copa Hill in Cwmystwyth, Nantyreira, Parys Mountain and Alderley Edge. The majority of the tools are hammerstones used to mine and beneficiate metal ore. Some of these have been modified to facilitate hafting.

The functional uses of these tools have been identified by the form and position of use-wear on a macroscopic level. The recording procedure encompasses cobble morphology, the degree, type and direction of use, breakage patterns, the reuse of tools and tool fragments and the classification of hafting modification. The possibility of tool specialization within tool types has been examined by the analysis of use-wear and cobble shape and size. The analysis of stone hammer size suggests that the Great Orme material is related to specific working techniques employed to extract ore from the different types of ore deposits. Ore comminution has been demonstrated to have been generally achieved by 'block-on-block' crushing with flat-sided hammers. Conclusions are draw on the overall efficiency of ore extraction in the Bronze Age and theories on the organization of mining are presented.

The sedimentary form of the cobblestone tools has also been examined, including the identification of natural abrasion marks and features. At Cwmystwyth and the Great Orme possible sources of cobblestones have been studied in order to assess the nature of cobble selection.

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ACKNOWLEDGEMENTS

The work was financed by a SERC studentship. My first thanks go to my supervisors for their invaluable advise and guidance; Dr Barbara Ottaway in my first year, and Professor Mark Pollard who very kindly took over on Barbara's departure to Sheffield.

The project would have not been possible without the help and assistance of Simon Timberlake, who very courteously allowed access to his material and much other information ahead of publication, and the members of Great Ormes Mines Limited, namely Andy Lewis, Tony Hammond and Edrick Roberts for allowing unlimited access to the Mine both above and below ground.

I am very thankful to the many people and institutions who provided me access to study their stone tool collections. They are Dr John Pragg of Manchester Museum, Stuart Needham of the British Museum, Dan Robinson of the Grosvenor Museum, Dr Green and Elizabeth Walker of the National Museum of Wales, Danny Dutton of the Gwynedd Archaeological Trust, Pete Crew at the Snowdonia National Park Study Centre, Julien Parsons at Sheffield City Museum, Frances Lynch of the Museum of Welsh Antiquities, Bangor, Mr A. Leigh of Warrington Museum and Art Gallery, Bryan Sitch of Hull Museum Services, Mrs Sandra Cruise of Rossendale Museum, Linda Mowatt of the Pitt-Rivers Museum, Andrew Sherratt of the Ashmolean, Angela Thomas of Bolton Museum, Ian Standing of the Dean Heritage Museum, members of Derbyshire Caving Club and Mr Brian Littleton, the National Trust Warden at Alderley Edge.

I am very grateful to Andy Lewis and Frank Jowett for their help with the rock identifications of the Great Orme material, Geoff Gaunt for identifying the Alderley Edge finds uncovered by the University of Bradford and Rob Janaway for volunteering to help with the beach survey on Great Ormes Head.

I am very indebted to all those people who provided information, references and discussion: Billy O'Brien, Paul and Brenda Craddock, Rob Ixer, Frank Jowett, Alan Tyler, John Pickin, Alan Garner and David Cranstone, to name a few. My work has greatly benefitted from discussion with my friends and colleagues Paul Budd and Richard Thomas.

I am very grateful to Janet Ambers for her help and guidance calibrating the radiocarbon dates and to my father for printing the copies of the black and white prints. I am also grateful to Jill for her painstaking reading and amendments. Finally, I would like to thank my wife, Bev for her continual support, encouragement and help.

For My Parents

CHAPTER ONE

Introduction

This thesis is concerned with the analysis of cobble tools used to extract copper ore from mine sites in England and Wales during the Bronze Age. These artefacts were used as rock-breaking and ore-dressing tools, and they are found contained within mine spoil in prodigious numbers, most generally at surface. They were either handheld or, as sometimes evidenced by modification to the midriff of the cobble, hafted by using a binding. Stone hammers which have been heavily used are commonly referred to as stone mauls. Most often, stone tools are the only form of material remains to survive, more especially so in surface contexts. In consequence, they form an important body of material evidence in the study of early mining.

In recent years, considerable attention has been paid to the identification of prehistoric metal mining remains in the British Isles. The five site assemblages studied for this thesis, four from Wales and one from England, have all been recently radiocarbon dated to the Bronze Age. In addition, they form part of a regional programme of fieldwork carried out by the Early Mines Research Group. Furthermore, it is only recently that sufficient numbers of mining tools have been made available for a study of this kind to be undertaken. There are two main objectives to this research: firstly, to see if it is possible to characterize mine working forms and mining techniques through examining stone tool types, and, secondly, to construct theories on how Bronze Age mining was organized and executed by analysing how these stone tools were procured and used.

In the first instance, the identification of extraction techniques through the analysis of stone tools would mean that prehistoric mining methods could be studied on a regional scale rather than just through individual, exceptionally well-preserved, sites. This is achieved by identifying tool types on the basis of evidence for macroscopic use-wear and damage, cobble morphology and modification for hafting, and then relating these to forms of mine workings and their geological structure. The second objective involves the study of the physical and morphological properties of selected cobbles in relation to their sources, and the analysis of tool consumption. By these approaches it may be possible to study how Bronze Age metalwork production was affected by ore extraction techniques and their organization.

In order to summarize the subject area, since the archaeological study of prehistoric metal mining is in its infancy, the results of recent site-based investigations together with earlier reports made by mining personnel and antiquarians are brought together in Chapter Two. This takes the form of discussions on the extent and scale of prehistoric mining, the mine types associated with stone tools and the dating of these remains. Mining techniques are described in detail, including that of stone tooling, and the forms of surviving prehistoric mine workings are examined. Previous studies of stone tools used to mine copper ore are surveyed in Chapter Three and areas of work requiring further investigation in relation to the objectives of this thesis are identified.

The tool assemblages analysed in this study are from the mine sites of Copa Hill in Cwmystwyth, Dyfed, the Great Orme in Gwynedd, Parys Mountain in north-east Anglesey, Nantyreira in Powys and Alderley Edge in Cheshire. The background to these site assemblages, i.e. their general description, archaeology, geological and mineralogical structure, and mining history, is described in Chapter Four. Potential sources of stone tool collections suitable for analysis are also surveyed.

The recording system devised for this study of cobble tools, which is described in Chapter Five, is divided into three areas; natural form, use-wear and haft modification. The natural form of the tool is concerned with the physical and morphological properties of the cobble. This includes surface marks and forms resulting from abrasion which may help to identify and characterize the sediment types from which they have been derived. Use-wear is recorded at a macroscopic level by its position on the stone, the type and composition of use-marks, and the resulting change in surface form. Modification for hafting is similarly recorded by its position on the stone, which relates to the complexity of the hafting arrangement, and by the degree and extent of working. Finally, the classification system for tool types is explained.

A detailed breakdown of the tool collections which make up the site assemblages is given in detail in Chapter Six. The assemblages are summarized by tool type and possible biases in their condition and composition are discussed. General observations are made concerning the composition of mining and ore-processing tools in relation to the geology of the sites and possible extractive strategies adopted during the Bronze Age (BA). The detailed description and analysis of the material is given in Chapter Seven, and involves the identification of rock and sediment types, and the analysis of cobble morphology and use-wear. Particular attention is paid to the question of whether or not mining hammers display functional specialization. With reference to the geology of the sites, these results are then discussed in more detail and inferences about prehistoric extractive conditions and other activities are made. In order to investigate the degree of selection and effort required in obtaining suitable cobbles for use as mining tools, cobble sources were examined in detail for two of the mine sites. This study is presented in Chapter Eight. Finally, in Chapter Nine, the conclusions of the work are presented, which involves the construction of theories about the organization of BA copper mining. Shape and use-wear measurements used in the analysis of cobble tools in this thesis are evaluated and recommendations for future work are also made.

CHAPTER TWO

Metalliferous Mining in Prehistory

2.1 Introduction

Although the existence of prehistoric metal mining remains was recognised as early as the mid-eighteenth century, few efforts were made to investigate these sites. It has only been in recent years, with the application of radiocarbon dating, that these remains have been demonstrated to date to the Bronze Age which, as a consequence, has generated considerable interest. The archaeological literature on early mining is devoted to the results of fieldwork and little attempt has yet been made to synthesize this work, partly because only a limited number of sites and regions have so far been investigated. This chapter summarizes these field studies, and draws together previous antiquarian work and site investigations, in order to present an up-to-date conspectus of prehistoric mining remains.

2.2 The discovery of prehistoric mining remains

The first report of early mining tools in the form of stone hammers, 'when Mankind knew no Tools but Stones', was made by the Crown Mineral Agent and antiquarian Lewis Morris in 1747 (Bick & Davies 1994, 37) for, what was then, the argentiferous lead mine of Twll y Mwyn (later incorporated with Cwm Darren), Dyfed (formerly Cardiganshire). Similar finds of stone hammers, in association with old fire-set workings, were described by Christopher Sykes in 1796 at the copper mines of Parys Mountain, Anglesey, and were considered to be of considerable antiquity (cited by Briggs 1976).

It was not until the Victorian literacy boom in the mid-nineteenth century that the extent of these 'old-man' workings became more apparent. These finds, however, generated only limited interest beyond the local antiquarian and archaeological society level and reports dwindled towards the end of the century with the decline of the copper and lead industries. It is, perhaps, noteworthy that contemporary mining literature is a poor source of reports of discoveries of ancient mining remains. For example, even for the Mid-Wales region, which is generously covered by three promotional booklets (Liscombe n.d. (c. 1869/70); Spargo 1870; Francis 1874), only two discoveries of these ancient remains are reported. In comparison, nine find sites for this region are documented in the archaeological literature. Furthermore, the Mining Journal, which is probably the most important nineteenth century documentary source for the mining historian, makes no mention of stone tool finds, although discoveries of 'old-man' workings are frequently referred to in the weekly progress accounts sent in by mine companies. In areas where old shallow workings were reworked, however, the discovery of stone tools cannot have been particularly unusual judging by the number of known find sites.

The open cut workings at Copa Hill, Cwmystwyth, associated with the recovery of cobble hammers, was first noted in the Memoirs of the Geological Survey in 1848 (Smyth 1848). At Great Orme, Llandudno, the discovery of extensive 'old-man' workings, containing stone hammers and numerous bones, appeared in the antiquarian column of the Gentleman's Magazine in late 1849. Finds from this site, as well as an earlier discovery, were presented by William Stanley, M.P., to the Archaeological Institute in the following year (Stanley 1850). In 1860 a further small collection of mining implements from Nantyreira (also known as Snow Brook) in Powys (formerly Montgomeryshire), including a stone hammer, were exhibited at the Institute (Anon 1860).

Other discoveries, made in North and Mid-Wales, were exhibited at the annual meetings of the Cambrian Archaeological Society. These finds included a stone hammer from Llancynfelin in 1850, and wooden spades, purported to be Roman, from Darren Mine, in 1859, 1861 and 1866. The exhibition at the 1866 meeting also included a large collection of stone tools from Darren Mine and a number of stone hammers from Blaendyffryn (Anon 1866) - also known as Nantyrarian. These were used to illustrate a paper presented by J.G. Williams (1866) who, most interestingly, interpreted these stone hammer finds as evidence of pre-Roman mining activity. In addition to the exhibited material and information about previously known sites, Williams also noted finds from Allt y Crib, Esgairhir and Rhiwrugos. Another find exhibited at the meeting (Barnwell 1870), but not described in any detail, included a stone hammer complete with an *in situ* withy handle, from Park Lodge (Ogof Wyddon) in Powys.

In England, two confirmed reports of early mining remains were made in the latter half of the nineteenth century. Thomas Bateman (1855) obtained stone hammers from Ecton Hill copper mine in Staffordshire in 1855, although nothing is known about the find (Hicklin, 1863, 66). In 1874 primitive mining pits containing a great number of stone hammers were discovered at Alderley Edge in Cheshire. Mining operations were then suspended for Professor Dawkins and Colonel Lane-Fox to examine the site. A brief description of the workings and stone tools was published in The Journal of the Anthropological Institute (Dawkins 1875). Further discoveries of primitive mine pits, unfortunately partly destroyed, and finds of stone hammers were subsequently made by Roeder and Graves at a number of other sites, including Mottram St. Andrew one mile to the east of the Edge (Roeder 1901; Roeder & Graves, 1905).

Claims of ancient mining activity in other mining districts include a stone hammer find from the Tyne Green mines in the northern Pennines (Wallace 1890, 1) and 'picks of stone' from the mines of Wanlockhead and Leadhills, Dumfriesshire (Hunter 1884).

In 1935 a committee was set up by the British Association for the Advancement of Science in order to investigate early mining sites in north and central Wales. Davies, the secretary to the committee, conducted limited excavations of mine tips known to yield stone hammers at Parys Mountain, Cwmystwyth, Great Orme and Nantyreira (Davies 1938; 1939; 1946; 1948).

For Ireland, similar discoveries of stone hammers from early mine tips were made in the nineteenth century in Co. Kerry and west Co. Cork, in association with fire-setting debris (O'Brien 1994, 5). Although the presence of stone tool finds were first reported from Mount Gabriel at the turn of the century, the earliest recorded investigation of the mine workings was not made until the late 1920s (O'Brien 1994, 48). Further examinations of the site were made in the late 1940s and early 1950s and, according to O'Kelly (quoted in Harbison 1966), a trial excavation was undertaken but no records of this survive. The obvious wealth of Early Bronze Age (EBA) Irish metalwork begged the question as to whether these remains of primitive mining activities represented the beginnings of copper metallurgy for the British Isles.

The first formal field study of these early Irish mining remains was undertaken by Jackson who completed a survey of the Mount Gabriel workings in 1962. He returned in 1966 to excavate a test trench through one of the mine tips and obtained, rather tantalizingly, a single radiometric date of 1686 to 1266 cal BC (i.e. the Middle Bronze Age) from a sample of charcoal fragments (Jackson 1968). This was an important breakthrough as it proved, contrary to the cautious beliefs held by many of Ireland's influential archaeological scholars, that these mines were of great antiquity and, perhaps, even more surprisingly, that such evidence of early mining activity survived intact.

Jackson subsequently identified a total of 74 similar mines or trials in South-West Ireland, including 31 at Mount Gabriel (Jackson 1979; 1980). These were assumed to date to the EBA because of their similarity in form to the dated Mount Gabriel working, together with the presence of stone hammers and the thickness of overlying peat.

Cowman (1982) dismissed Jackson's claims of probable Bronze Age mining of one such site at Danes' Island by suggesting that stone hammers could have been used as late as the nineteenth century. Briggs (1983) rejected the possibility of Bronze Age mining at Mount Gabriel outright, questioning the context of the Mount Gabriel radiocarbon sample. He suggested, rather incredulously, that a spurious C14 date had been obtained from burnt peat which could have derived from fire-setting at any time up until very recently. This objection was overturned when Jackson obtained a radiocarbon date of 1740 to 1130 cal BC, for the base of the peat sealing the mine tip (Jackson 1984).

Meanwhile, interest in the possibility of early mining in Wales was renewed. Members of the North Wales Caving Group and, later, the Great Orme Exploration Society carried out detailed exploration of the underground mine workings at Great Orme from 1976. A radiocarbon date of 1395 to 935 cal BC (table 2.1) was eventually obtained in 1986, from charcoal contained in old pack (deads) in the region of Roman Shaft, Bryniau Poethion, at a depth of about 30 metres (James 1988). At Copa Hill, Cwmystwyth, Timberlake obtained three radiocarbon dates to the Early to Middle Bronze Age (table 2.1) from a section of early mine tips associated with an opencast working (Timberlake 1988a; Timberlake & Switsur 1988). These discoveries in Wales resulted in the formation of the Early Mines Research Group in 1986.

The Group, with the support of The British Museum, undertook limited excavations in 1988 at the two other early mining tips first investigated by Davies, namely Parys Mountain and Nantyreira, which were also dated to the Bronze Age (Timberlake 1989). Over the last five years the Group carried out short fieldwork seasons at Copa Hill, on the tips and the fill of the opencast working (described in more detail in section 4.2.4) and trial excavations at Llancynfelin and Nantyrarian from which prehistoric dates have been obtained (table 2.1).

SAMPLE	UNCALIBRATED RADIOCARBON DATA BP	CONTEXT	MATERIAL	ANALYSIS OF PROBABILITY DISTRIBUTION (cal BC/AD)		REFERENCE
				1 SIGMA ERROR 68% CONFIDENCE LEVEL	2 SIGMA ERROR 95% CONFIDENCE LEVEL	
<u>NANTYREIRA</u> BM-2581	3390 ± 80	Surface spoil	Mature birch and oak branchwood	1880 to 1840 BC or 1820 to 1800 BC or 1780 to 1610 BC or 1560 to 1540[1] BC	1884 to 1510 BC or 1470 to 1468 BC	Timberlake 1989
BM-2583	3410 ± 50	Surface spoil	Mature birch and oak branchwood	1875 to 1840 BC or 1775 to 1670 BC 1655 to 1650[1] BC	1885 to 1610 BC	Timberlake 1989
<u>PARYS MOUNTAIN</u> BM-2584	3550 ± 50	Surface spoil	Mature oak branchwood	2015 to 2005 BC or 1975 to 1870 BC or 1840 to 1780[1] BC	2035 to 1750 BC	Timberlake 1989
BM-2585	3490 ± 50	Surface spoil	Mature oak branchwood	1885 to 1755[1] BC	1945 to 1685 BC	Timberlake 1989
BM-2586	3500 ± 50	Surface spoil	Mature oak branchwood	1890 to 1755[1] BC	1965 to 1690 BC	Timberlake 1989
<u>LLANCYNFELIN</u> BM-2916	3390 ± 35	Surface spoil	Immature oak & alder charcoal	1745 to 1670 BC or 1655 to 1645[1] BC	1875 to 1840 BC or 1775 to 1610 BC	Ambers (pers. comm.)
BM-2929	1000 ± 60	Pit	Wood	970 to 1050 AD or 1080 to 1155[2] AD	895 to 1165 AD	Ambers (pers. comm.)
<u>NANTYRARIAN</u> BM-2930	3470 ± 60	Surface spoil	Charcoal	1885 to 1735[1] BC	1960 to 1645 BC	Ambers (pers. comm.)
<u>ALDERLEY EDGE</u> OxA-4050	3470 ± 90	Unknown	Mature oak (shovel)	1910 to 1685[1] BC	2035 to 1595 BC or 1565 to 1525 BC	Garner et al 1994

Table 2.1 Radiocarbon dates for early metal mining sites in England and Wales

Dates calibrated using OxCal v2.14.
References refer to first publication of uncalibrated date.

SAMPLE	UNCALIBRATED RADIOCARBON DATA BP	CONTEXT	MATERIAL	ANALYSIS OF PROBABILITY DISTRIBUTION (cal BC/AD)		REFERENCE
				1 SIGMA ERROR 68% CONFIDENCE LEVEL	2 SIGMA ERROR 95% CONFIDENCE LEVEL	
GREAT ORME BM-2752	3070 ± 50	Spoil within stope	Collagen from bone fragments	1415 to 1300 BC or 1275 to 1270[1] BC	1450 to 1210 BC or 1180 to 1165 BC	Dutton et al. 1994
BM-2751	3230 ± 50	Spoil within stope	Collagen from bone fragments	1595 to 1565 BC or 1530 to 1440[1] BC	1635 to 1415 BC	Dutton et al. 1994
CAR-1281	2450 ± 60	Surface working	Oak, alder & hazel charcoal	765 to 630 BC or 600 to 415[1] BC	770 to 405 BC	Dutton et al. 1994
CAR-1280	2970 ± 70	Surface workings	Oak & hazel charcoal	1370 to 1350 BC or 1320 to 1090[1] BC	1400 to 1010 BC	Dutton et al. 1994
HAR-4845	2940 ± 80	Tunnel working 27m below surface	Charcoal	1295 to 1030[1] BC	1395 to 935 BC	James 1988
BM-2641	3000 ± 50	Tunnel working 20m below surface	Immature oak charcoal	1380 to 1340 BC or 1320 to 1160[1] BC	1410 to 1070 BC	Jenkins & Lewis 1991
BM-2645	3290 ± 60	Floor of sub-surface gallery	Collagen from bone fragments	1675 to 1515[1] BC	1735 to 1440 BC	Jenkins & Lewis 1991
CAR-1184	3370 ± 80	Floor of sub-surface gallery	Alder charcoal	1760 to 1595 BC or 1570 to 1525[1] BC	1890 to 1505 BC	Jenkins & Lewis 1991
BM-2802	3180 ± 80	Surface working	Oak & alder charcoal	1595 to 1565 BC or 1530 to 1390 BC or 1335 to 1325[1] BC	1675 to 1265 BC	Dutton et al. 1994
BM-2753	1200 ± 60	Fynnon Galchog washing site	Collagen from bone fragments	720 to 740 AD[2] or 760 to 895 AD	680 to 960 AD	Ambers (pers. comm.)

Table 2.1 (continued) Radiocarbon dates for early metal mining sites in England and Wales

SAMPLE	UNCALIBRATED RADIOCARBON DATA BP	CONTEXT	MATERIAL	ANALYSIS OF PROBABILITY DISTRIBUTION (cal BC/AD)		REFERENCE
				1 SIGMA ERROR 68% CONFIDENCE LEVEL	2 SIGMA ERROR 95% CONFIDENCE LEVEL	
COPA HILL BM-2759	2850 ± 80	Floor of small mine gallery in the wall of the open cast	Leaf & moss peat	1155 to 910[1] BC	1265 to 840 BC	Timberlake 1991b
BM-2812	3460 ± 50	Base of open cast	Immature oak charcoal	1880 to 1735[1] BC	1915 to 1675 BC	Timberlake & Mighall 1992
Q-3077	2990 ± 190	Surface mine spoil	Charcoal	1440 to 990 BC or 955 to 945[1] BC	1675 to 810 BC	Timberlake 1987
Q-3076	3220 ± 70	Surface mine spoil	Charcoal	1605 to 1555 BC or 1535 to 1425[1] BC	1680 to 1385 BC or 1335 to 1325 BC	Timberlake 1987
Q-3078	3210 ± 50	Surface mine spoil	Charcoal	1525 to 1430[1] BC	1620 to 1410 BC	Timberlake 1987
BM-2732	3500 ± 50	Open cast infill	Immature oak charcoal (oak?)	1890 to 1755[1] BC	1965 to 1730 BC or 1725 to 1690 BC	Timberlake 1990a
BM-2733	3070 ± 50	Open cast infull	Peat	1415 to 1300 BC or 1275 to 1270[1] BC	1450 to 1210 BC or 1180 to 1165 BC	Timberlake 1990a
BM-2908	3690 ± 90	Base of open cast	Wooden launder of hollowed out tree trunk)	2275 to 2255 BC or 2205 to 1950[1] BC	2455 to 2425 BC or 2395 to 1875 BC	Timberlake 1993

[1] Pearson & Stuiver 1986

[2] Stuiver & Pearson 1986

Table 2.1 (continued) Radiocarbon dates for early metal mining sites in England and Wales.

At Great Orme a mine reclamation scheme, begun late in 1987, initiated an underground mine survey and surface excavations in the region of Vivian's Shaft, Pyllau. This work is described in detail in section 4.1.4. Extensive prehistoric mine workings were discovered both underground and buried at surface by mine spoil from which radiocarbon dates to the Bronze Age have been obtained (table 2.1). The site has since been privately developed into a visitors' centre by the Great Orme Mines Limited to display the Bronze Age workings, both above and below ground, to the public. Small excavations at surface and below ground are ongoing.

The Mount Gabriel workings were re-examined by O'Brien, including a mineralogical and palaeo-environmental study, together with a thorough programme of radiocarbon dating (O'Brien 1987; 1990; 1994; O'Brien *et al.* 1990). The excavation strategy was aimed specifically at relating mining and processing activities at a single mine trial known as 'Mine 3'. Wood artefacts were recovered from waterlogged sediments within the mine and an associated 'activity area' on the periphery of the spoil heap was identified. Ten further C14 dates were obtained, confirming the main period of mining activity dates to between 1700-1500 cal BC, i.e. the closing stages of the EBA (Brindley & Lanting 1990). More recently, large scale excavations have been undertaken since 1992 by O'Brien at Ross Island, County Kerry, uncovering two early copper workings and the first associated settlement remains (O'Brien 1994, 229). In addition to worked flint and animal bone, small quantities of early Beaker pottery and metallurgical debris have also been recovered. So far eight radiocarbon dates have been published indicating that the mines were in operation prior to 2000 cal BC and thereby making it the earliest copper mine in North-west Europe. Full details are yet to be published.

2.3 The identification and extent of prehistoric mining remains

Field and documentary surveys by members of the Early Mines Research Group identified finds of stone tools from 25 mine sites in Wales (Pickin 1988; 1990). Fifteen out of a total of nineteen early documentary reports were confirmed in the field (tables 2.2 & 2.3). This demonstrates that, in spite of more recent mining at the sites, usually in the nineteenth century, extensive remains have survived. The assumption that early metalliferous mining remains have been obliterated by successive generations of mining (e.g. Barnes 1979) is not always true. Similarly, the belief that prehistoric copper mines are rare and that wide scale mining did not evolve until the Roman period (Shepherd 1980, 170) is no longer tenable. Cobblestone tools, by their very nature, are extremely durable artefacts and can be identified even in residual, disturbed and redeposited contexts. This is important, since most find reports recently confirmed in the field are from secondary contexts or show some level of disturbance to their discovery.

The distribution of these sites is generally restricted to certain mineral districts and is not representative of the historically productive copper, or metalliferous, mining districts of Britain (fig. 2.1 & 2.2). Recent mining operations at these early sites would seem to indicate that this distribution is not related to particular geological or mineralogical conditions, since a variety of ores were extracted prehistorically from a range of host rocks and in variable modes of occurrence. Moreover, the discovery of these ancient sites cannot be explained in terms of variations in recent regional mining practices. Find sites in the Mid-Wales mining district, however, are associated with worked out minor deposits of copper ore (chalcopyrite) at mines known historically for the production of lead and zinc. Although the identification of these sites is dependent on the disturbance of prehistoric tip material by recent prospecting or mining, this activity has been generally less damaging due to the marginal position and the poorness of these deposits. This may explain why remains have not

Mine site	NGR	Ore type	References
Gwynedd			
Great Orme	SH771832	Cu	Stanley 1850, James 1988, Lewis 1990a, 1990d, Dutton *et al.* 1994
Moel Hebog	SH558472	Cu	Breese 1908
Parys Mountain	SH445905	Cu	Davies 1939, Timberlake 1988d & 1990d
Powys			
Nantyreira	SN827874	Pb/Cu	Davies 1938, Timberlake 1990d
Nantyricket	SN865867	Cu	Jones 1922, Pickin 1988
Dyfed			
Allt y Crib	SN648894	Pb/Cu	Pickin 1990
Cwmystwyth	SN816756	Cu	Davies 1946, Timberlake 1987, 1988b, 1990a, 1990c
Darren	SN681833	Pb/Cu	Pickin 1988
Dolclettwr	SN658919	Pb/Cu	Pickin 1988
Erglodd	SN657904	Pb/Cu	Hughes 1981a, Pickin 1988
Esgairhir	SN735912	Pb/Ag	Williams 1866, Pickin 1988
Esgairlle	SN791829	Pb	Hughes 1981a, Pickin 1988
Grogwynion	SN714724	Pb/Zn	Pickin 1988
Hafan	SN730880	Pb	Hughes 1981a, Pickin 1988
Llancynfelin	SN651921	Pb/Cu	Anon 1850, Pickin 1988
Nant y Creiau	SN791803	Pb	Hughes 1981a, Pickin 1988
Nantyrarian	SN705814	Pb/Cu	Williams 1866, Pickin 1988
Twll y Mwyn	SN683834	Pb/Cu	Williams 1866, Pickin 1988
Cheshire			
Alderley Edge	SJ8677	Cu	Dawkins 1875, Roeder 1901, Roeder & Graves 1905
Staffordshire			
Ecton Hill	SK0958	Cu/Pb	Hicklin 1863
Isle of Man			
Bradda Head	SC183698		Pickin & Worthington 1989

Table 2.2 Confirmed reports of stone hammer finds from British metal mines (after Pickin 1990).

Mine site	NGR	Ore	References
Gwynedd			
Corbet Dovey	SN617992	Cu	Pickin 1990
Panteidal	SN661974	Cu	Bick 1990a
Pant y Casseg	SH412945	Cu	Pickin 1990
Penrhyn-du	SH3129	Pb	Williams 1871
Snowdon	SH616547	Cu	Breese 1908
Trecastell	SH760746	Pb/Zn	Peake 1937
Powys			
Parc Lodge (Ogf Widdon)	SN760001	Cu	Barnwell 1870
Dyfed			
Cwmsymlog	SN700837	Pb/Ag	Spargo 1870
Penpombren	SN658901	Pb/Ag/Cu	Mining Journal 1869, 39(1763), 400
Rhiwrugos	SN714783	Pb/Zn	Williams 1866
West Glamorgan			
Brandy Cove	SS586874	Pb	Pickin 1990
Cumbria			
Tyne Green	NY7534	Pb/Cu	Wallace 1890
Dumfries & Galloway			
Wanlockhead/Leadhills	NS8613	Cu/Pb	Hunter 1884

Table 2.3 Unconfirmed reports of stone hammer finds from British metal mines (after Pickin 1990).

Fig. 2.1 British metal mines associated with stone hammer finds: ▲ confirmed find, △ unconfirmed find. Key: 1, Wanlockhead/Leadhills; 2, Tyne Green; 3, Bradda Head; 4, Alderley Edge; 5, Ecton Hill; 6, Brandy Cove.

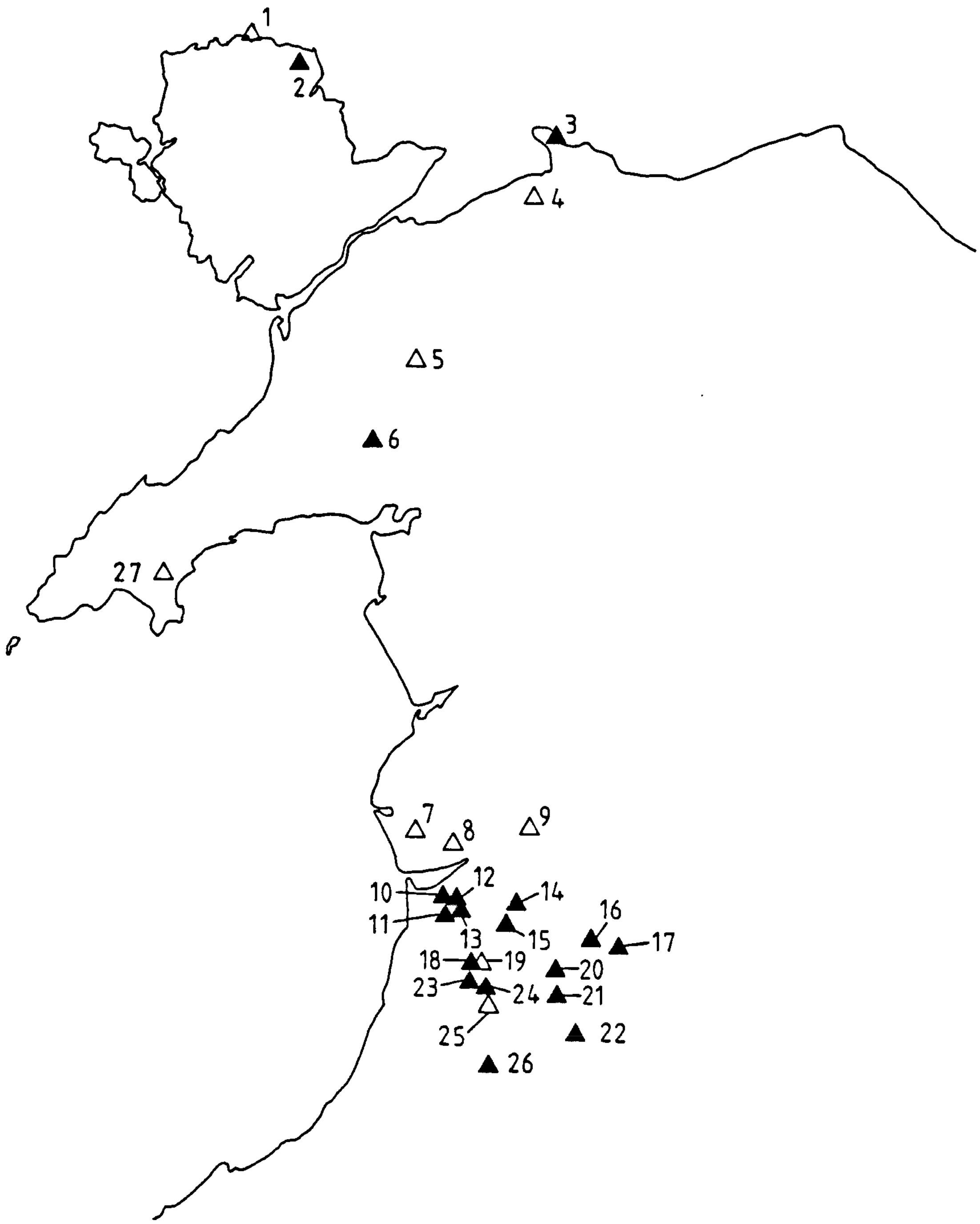


Fig. 2.2 Metal mines in North and Mid-Wales associated with stone hammer finds: ▲ confirmed find, Δ unconfirmed find. Key: 1, Pant y Casseg; 2, Parys Mountain; 3, Great Orme; 4, Trecastell; 5, Snowdon; 6, Moel Hebog; 7, Corbet Dovey; 8, Panteidal; 9, Parc Lodge; 10, Llancynfelin; 11, Allt y Crib & Penpombren; 12, Dolclettwr; 13, Erglodd; 14, Esgairhir; 15, Hafan; 16, Nantyreira; 17, Nantyricket; 18, Darren; 19, Cwmsymlog; 20, Esgairlle; 21, Nant y Creiau; 22, Cwmystwyth; 23, Twll y Mwyn; 24, Nantyrarian; 25, Rhiwrugos; 26, Grogwynion; 27, Penrhyn-du.

been found in other mining districts, where the mineral deposits are much larger and the mines have been repeatedly worked specifically for copper. Nevertheless, it would seem likely that early mining activity survives much more extensively than suggested by the sites identified so far, since many remains are probably buried beneath later spoil or are unrecognizable surface features as a result of weathering and natural soil formation. It would seem to be only a matter of time before further discoveries are made in other metalliferous areas which are presently 'without sites', most notably Cornwall, the Lake District and Scotland, as fieldwork moves away from areas for which there is literary evidence.

2.4 Mine types associated with stone tooling

Cobblestone tools found on mine sites are generally regarded as indicators of copper mining, chiefly on the basis of a number of field studies in Europe and beyond; namely Chinflon in southern Spain (Rothenberg and Blanco-Freijeiro 1981), Rudna Glava in Serbia (Jovanović 1976; Jovanović & Ottaway 1976), and Aibunar in Bulgaria (Černych 1978). These sites suggest that cobblestone tools were used exclusively to mine copper ore in the Chalcolithic and EBA, and that they were succeeded by bronze and iron tools in the Late Bronze Age (LBA). Cobblestone tools have, more recently, been found in prodigious numbers at a mine in central Turkey, called Kestel, dating to the EBA and possibly Middle Bronze Age (MBA) for which tin, other metals or minerals may possibly have been extracted (Yener *et al.* 1989; Willies 1990).

In the British Isles, this association of stone tools with early copper extraction has been confirmed by the recent archaeological investigations at sites in Wales and southwest Ireland. These, as well as other stone tool find sites, include several historically productive copper mines (Llandudno Copper Mine, Alderley Edge copper mines, Mona and Parys Mines, and Ecton Mine), whilst a number of others, for example Nantyreira, were worked historically for both copper and lead. This association with copper minerals cannot be more obvious than at Cwmystwyth. Although this was predominantly mined historically for argentiferous lead, the only evidence for prehistoric mining has been found on the single copper vein, Comet Lode. At a number of other historical lead mines, stone hammers are found in relation to small, uneconomic, chalcopyrite deposits having been left largely undisturbed by the later activity. Furthermore, only lead/zinc ores have been recorded for a number of sites. The appearance of leaded bronze early in the MBA in Wales, interpreted as a deliberate alloy by Northover (1982) for the purpose of improving casting properties, has led to the suggestion that lead rather than copper ores may have been extracted at some of these mine sites. Attention has also been drawn to the possibility that silver-rich galena may have been exploited in Mid-Wales (Bick 1990b). Although this would seem rather unlikely during the Bronze Age, Gowland (1920) had previously suggested that silver could have been relatively easy to produce by smelting cerargyrite. It is also likely that copper minerals have gone unrecorded at some of these sites. They may have occurred as trace or historically uneconomic deposits, particularly as surface oxidized ores, or, they may have been exhausted during an earlier period of mining. Moreover, it should be remembered that most mine sites are mineralogically poorly documented.

There have been a number of antiquarian reports of stone tool finds made in the contexts of iron and coal mining but these remain unsubstantiated. In the case of coal mining two discoveries have persisted throughout the literature. The first reference, made in 1778 (Pennant 1778, vol. 1, 25), is to a flint axe 'discovered stuck in certain veins of coal, exposed to day [*sic*] in Criag y Parc in Monmouthshire'. The second reported discovery (Hull 1873, 15) was made in old workings at Measham near Ashby-de-la-Zouche in Leicestershire, which consisted of 'stone hammer heads, flint wedges with hazel withes round them, and solid wheels about 18 inches in diameter' (Fox-Strangways 1907). A further citation by Davies

(1935) to finds of stone wedges in coal mining contexts for workings near Ballycastle in County Antrim is incorrect, as the original reference described these 'rude implements' as being tipped with iron (Holden 1868).

For iron mining, Richardson and Tweddle (1880, vol. 2, 38) described the discovery of two polished stone axes and an iron implement from underground 'old-men workings' at Stainton in Furness. The accuracy of this report is questionable, especially in view of the authors' claim that the copper mines of Coniston had been worked by 'Ancient Britons', and 'their rude implements are not infrequently found in some of the very old workings' (1880, vol. 1, 254) as there are no contemporary reports of such findings.

Two possible cobble tools have been recovered more recently from an iron mine in the Forest of Dean (Standing pers. comm.) and these have been examined by the author. These were found in different areas within the underground workings at Noxon Park, Bream. Both of the stones are small, well-rounded, intra-clastic limestone cobbles, i.e. rocks contained within these churn deposits and liberated by mine working. The first cobble was recovered from re-stacked deads in the Jetty Entrance/Big Collapse area, some 50 feet below ground surface and 150 feet from the outcrop hole. It is fairly small, measuring 100 x 86 x 56mm, and had been clearly used at both ends, exhibiting evidence of hard, but minor, pounding resulting in small cupped facets (fig 2.3A). These work marks would seem to indicate precise blows to a hard, sharp instrument, most probably of iron. The second find, recovered from deep workings in the Middle Rift area, some 150 feet below ground and 500 feet from the outcrop hole, did not appear to have been worked (fig 2.3B). The mine working from which they were found is undated, although it appeared to have been enlarged in the nineteenth century, due to the presence of shot holes, in order to provide access to deeper workings. In conclusion, in the absence of further finds, it would not seem possible to ascribe this find to early mine working.

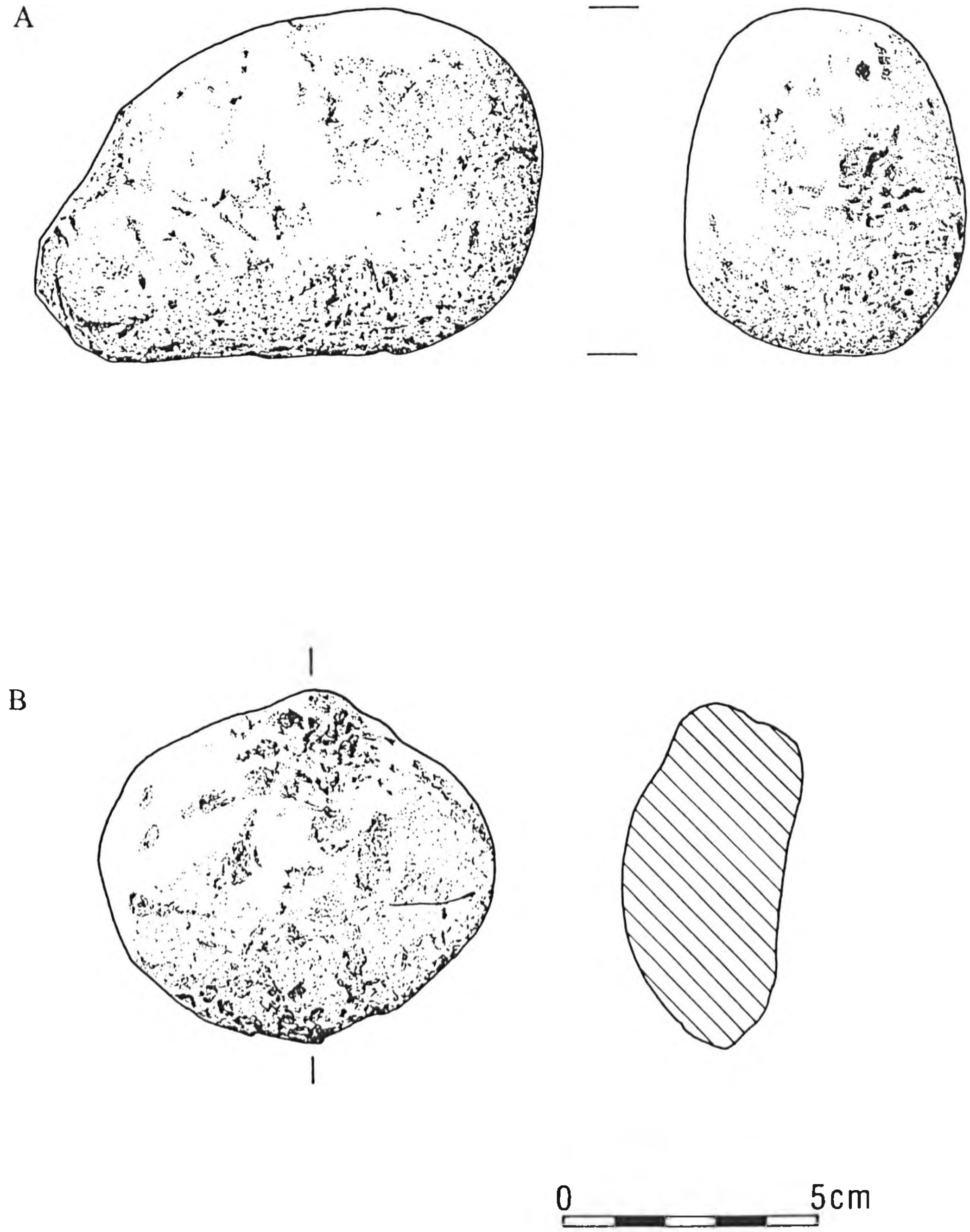


Figure 2.3 Possible stone hammers recovered from an iron mine, Noxon Park, Bream, in the Forest of Dean: A - found in the Jetty Entrance and Big Collapse area; B - found in the Middle Rift area.

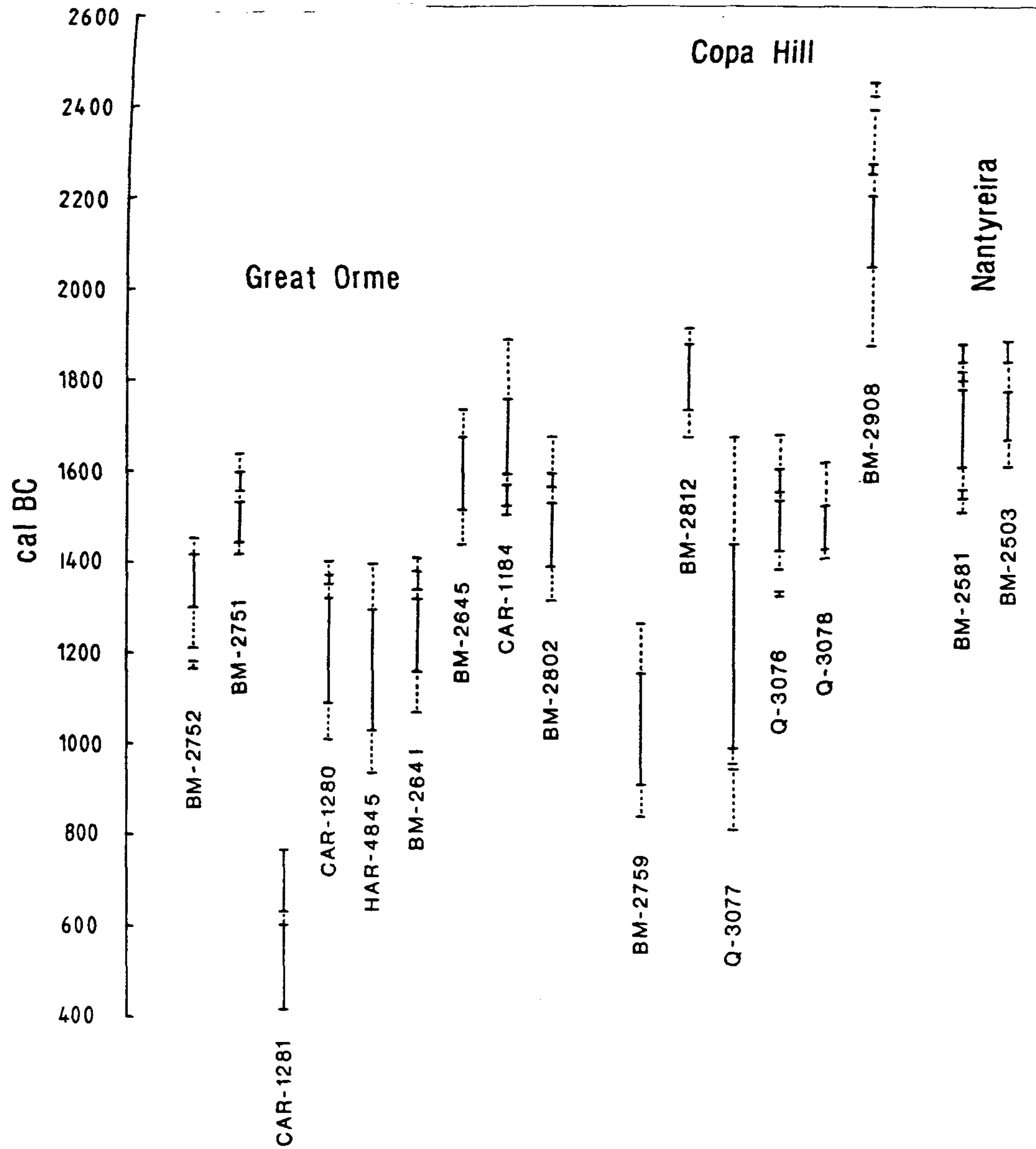
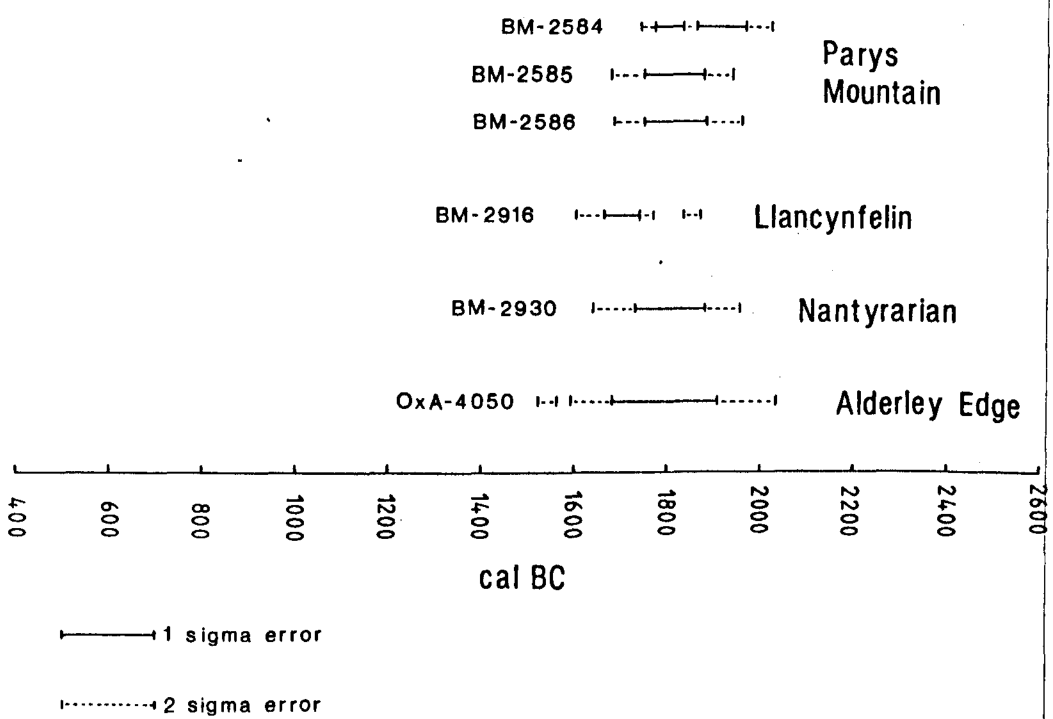


Figure 2.4 Radiocarbon dates for early metal mines in England and Wales.


BM-2584
BM-2585
BM-2586
Parys Mountain
BM-2916
Llancynfelin
BM-2930
Nantyrarian
OxA-4050
Alderley Edge
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
cal BC
1 sigma error
2 sigma error

2.5 Dating of stone tools employed in metalliferous mining

Before the application of radiocarbon dating to the dating of early mining remains, many scholars were cautious in attributing stone hammers to prehistoric mining activity. O'Kelly warned that these could just as easily be early Medieval as EBA (Harbison 1966), a view also expressed by Tylecote (1986, 12). A number of mining historians have suggested, moreover, that stone mauls may have been employed as late as the eighteenth century (Cowman 1982; Warrington 1981) despite the absence of any documentary evidence to support such claims.

Radiocarbon dating has so far established that all mines worked with stone hammers are dated to the Bronze Age. Unlike other areas of Europe, for instance Serbia and Iberia, where stone hammers were used only during the Chalcolithic and EBA, the dates suggest that they were used throughout this period. On the other hand, stone tools used in ore-dressing, for example cobbing hammers, were certainly used in some mining districts until the Medieval period (Buckley & Earl 1990).The dating relationship between mining and ore-dressing tools for the other areas of Europe are not, as yet, known. Ore-dressing tools and their form are discussed in more detail in section 2.8.

2.6 Dating of prehistoric mining remains

Prehistoric mining activity has been identified for six sites in Wales and one site, Alderley Edge, in England by radiocarbon dating of charcoal, bone collagen, wood and peat, from mine spoil contexts. These dates are presented in table 2.1 and all fall within the Early to Late Bronze Age. Samples dated by the British Museum Research Laboratory up until 1989 are discussed in detail by Ambers (1990). Attempts are being made to develop other dating techniques to date calcitic flowstone found sealing prehistoric pack underground at the Great Orme. So far only a single date, at around 2600 BP, has been obtained using uranium series dating (Lewis 1994).

It should be remembered that some of the samples may not be from primary mine spoil contexts, as they may have been redeposited or disturbed by later mining activity which may, or may not, be recognizable. Primary spoil in underground workings can only be identified with absolute certainty in specific contexts. (Continued on page 23a.)

Radiocarbon dating has proved to be the only means of dating these sites so far as no datable or corroboratory artefactual material has been found. For the Bronze Age copper mines of southwest Ireland two associations with stone axes have been claimed: a possible hoard of flint axes from Ballyrisode (Caulfield 1880 cited by Jackson 1968), and an undated and loosely provenanced stone battle-axe find (Simpson 1990). The reliability of the former report has been questioned by Briggs (1983; 1984). A battle-axe find from Foxdale Mine on the Isle of Man (Pickin & Worthington 1989)[1] is a further example of such a loose association. Although these may have been discovered as a result of modern mining operations, this does not necessarily mean that they are connected with ancient mine workings. It is possible that they were uncovered during road and building construction at the mine site. It should not be forgotten that examples of grooved stone tools, often described as miners' tools, have been recovered during construction work at sites unrelated to mining. For example, a grooved stone maul was found in the overburden of a limestone quarry at Greenleighton, Northumberland (Smith 1963).

The dating hiatus in mining activity from the Iron Age to the post-Medieval period, with the exception of four Roman mines (Tyler 1982), can perhaps, be best correlated with metal tooling, used either alone or in conjunction with fire-setting. Although studies have been made of metal tooling marks in an attempt to characterize periods of working (e.g. Weisgerber 1985, 97), these cannot be used as a dating technique, due to the lack of reliable dating associations.

Briggs (1983; 1988; 1991a; 1991b) has attempted to refute the dating for Bronze Age extraction at Mount Gabriel, Cwmystwyth and the Great Orme by claiming that peat or bogwood, used historically as fire-setting fuel, and hydraulic processes have given rise to

For comparative purposes, the calibrated radiocarbon dates for prehistoric mining contexts only, taken from table 2.1, are plotted in figure 2.4. The date ranges suggest that many of the sites were exploited contemporaneously from around 2000 to 1500 cal BC. It should be borne in mind, however, that the dates for Parys Mountain and Nantyreira are obtained from mature wood which may give rise to some age effects (Ambers 1990). For Copa Hill, two dates have been obtained from the base of the opencast. One date has been obtained from the wooden launder of unidentified tree species which, although yielding the earliest date, may too be subject to age effects. The other date obtained from immature oak charcoal may be considered to be more closely contemporary with the mining activity. It should be noted that this date is comparable with activity at the other mid-Wales sites. The date obtained from leaf litter covering the base of the small gallery suggests that this was worked later but the dates from the surface tip do not prove conclusively that this was a separate phase of activity.

The dates obtained from the Great Orme are generally later although the underground mining had developed relatively quickly by 1600 - 1400 cal BC. The three dates obtained from material in surface contexts show a wide dating distribution including one date to the closing stages of the Late Bronze Age/Iron Age which has been suggested to be linked to a later phase extracting the harder chalcopyrite ore (Dutton *et al.* 1994). From the present suite of radiocarbon dates it is difficult to comment on the development of mine working forms and the scale of prehistoric mining at the Great Orme.

incorrect dating associations. These claims have been countered by Jackson (1984), Craddock (1986), O'Brien (1987), Timberlake (1988a; 1990a; 1991a), Timberlake and Mighall (1992) and Budd *et al.* (1992). The suggestion that bogwood or peat could have been used as fire-setting fuel in recent times is fundamentally flawed because none of the documentary evidence presented mentions this use. Furthermore, the proposed source of bogwood at Copa Hill is too young to have produced the radiocarbon dates obtained from the mine (Timberlake & Mighall 1992). It can only be concluded that the dating views held by Briggs are completely at odds with the wealth of archaeological and scientific evidence amassed over the last ten years and that his objections can no longer be taken seriously.

2.7 Mining Techniques

These are traditionally discussed in terms of prospection, extraction techniques, tooling, lighting, ventilation, drainage, access, propping, haulage and transport. For the ensuing discussion it will become obvious that these technical divisions are either irrelevant or, due to the lack of recoverable or surviving remains, unknown. The discussion is further limited by the fact that few prehistoric workings survive intact in England and Wales. Mount Gabriel has also been included as excavations have recovered an appreciable assemblage of waterlogged wooden artefacts from one mine working which are not represented at the other sites.

It should be stressed that mine workings are generally found to be deficient in artefactual remains as a result of poor preservation conditions, except in the case of waterlogged sediments.

2.7.1. Prospection

It is difficult, if not impossible in some cases, to imagine the surface form of many of the lodes prior to mining because no comparable unworked deposits survive today. It is likely that prospection techniques relied on the visual inspection of outcrops and stream beds, and, most probably, the recognition of vegetational changes and metallophytic plants. It should be stressed, however, that prospection techniques could not have been wholly dependent on outcropping exposures since, for example, some of the mineralized veins at Alderley Edge, most notably Brynlow Levels, were worked although they would have been unexposed.

There is no confirmed evidence that physical prospection techniques differed from those employed for extractive mining. At Mount Gabriel, for instance, O'Brien (1990) has classified workings into surface 'fire-trials', where they are less than one metre in depth, more substantial surface trials of one to three metres in depth, and more productive mines of up to 12 metres in depth. Apart from the length of the workings, there are no other criteria for differentiation between the workings, so that 'trials' became 'mines' as long as the ground remained favourable. All the workings can be considered as 'extractive' as the Bronze Age miner was working productive ground rather than 'productive' mines.

Hushing, a hydraulic method of prospection and exploitation using controlled bursts of water and described by the Elder Pliny, has been characterized as a Roman mining technique employed extensively in north-west Spain for alluvial and hard rock gold mining (Bird 1972; Lewis & Jones 1970). At Dolaucothi, Dyfed, for which there is now good dating evidence for Roman mining (Burnham 1990), four leat systems supply a series of tanks and reservoirs above the opencast workings (Lewis & Jones 1969). Two radiocarbon dates have recently been obtained from peat within one of these channels (793 to 953 and 894 to 1011 cal AD) and these suggest that the leat systems are Roman in date (Jones & Maude 1990).

In the absence of documentary records, the dating of hushing channels is generally very problematic. Hushing channels, pre-dating eighteenth century activity, are related to the prehistoric opencast working at Copa Hill, Cwmystwyth, but there has been no direct suggestion that these features are prehistoric. A feature cutting the original ground surface beneath the prehistoric tip at Site C has been interpreted as a possible artificial stream channel (Timberlake 1987), but the irregular form of this feature may suggest that it is natural.

2.7.2. Working

Prehistoric mine workings, as represented by Cwmystwyth, Great Orme, Alderley Edge and Mount Gabriel, were entirely extractive in nature, i.e. they involved the removal of the minimum of barren ground in order to extract productive ore. Consequently, the form of working is dictated by the inherent geological and mineralogical conditions of each mine, and, although workings such as Mount Gabriel have been described in terms of regional 'types', none of these workings can be considered 'regular'. Regular forms of workings are first recorded for Roman mining practices, and in Britain these are noted at Dolaucothi (Hall 1971, 39).

At Great Orme several forms of prehistoric working have been employed to mine fault zone veins, the surrounding ore impregnated country rock, and mineral enriched shale beds interbedded within the limestone strata. At the surface the main lodes have been mined by opencasting and trenching to depths of 16 and 15m respectively, while more minor veins and cross-veins have been worked by trenching and tunnelling. The underground workings consist of a labyrinth of small, sometimes tortuous, tunnels and chamber-like workings up to 15m in height (Lewis 1990a). These workings have, so far, been surveyed to depths of 70m, extending along the 110m width of mineralization, for a length of 250m.

At Cwmystwyth, the Comet Lode has been worked by opencasting to form a deep trench-like feature, 45m in length, to a depth of 12m or possibly more. At a depth of 7m (2½m from the surface of the present day infill) small, irregular, side workings in the north wall followed stringers (Timberlake 1990a). Very recent excavations at the front of the opencast have shown that its base consists of a number of narrow trenches working small parallel veins, very much like the surface workings at Great Orme, leaving shelves or benches in between (Timberlake 1993).

At Alderley Edge, mineralized fault lines were worked by surface pitting. Relatively undisturbed pits were recorded at Brynlow in 1874 (Dawkins 1875), which measured between 5 and 20 feet (1.5 and 6.1 metres) in depth and up to 17 feet (5.2 metres) in width.[2] Further pits were subsequently recorded at Engine Vein and Pillar Mine (Roeder 1901; Roeder & Graves 1905), although partially destroyed by later working. The surviving form of these pits suggested that the mineralized fault zones were worked by both discrete and continuous pitting. The maximum surviving depth of the Engine Vein workings is 4 metres but they were originally deeper before the destruction of the pit bottoms by later stoping (Gale 1989). The pits are characteristically smooth and rounded with incut hollows.

It is often difficult to surmise the size and form of possible prehistoric mine workings from antiquarian reports mainly because the circumstances of the finds, sometimes undoubtedly of mixed age, are not given in sufficient detail. Although it is tempting to assign finds of stone tools made underground to the potential existence of developed prehistoric underground workings, the possibility that these implements may have fallen from higher workings, which may have been cut from below by more recent mining, must be considered. Such a situation was recognized for the openwork at Engine Vein, Alderley Edge, by Roeder and Graves (1905). Nevertheless, there are a surprising number of reports about ancient workings containing stone tools, to give an adequate indication of the form of the working. Some examples are sufficiently helpful in that they can be used to contribute to our understanding of the general form and techniques of prehistoric mining.

At Parys Mountain the possible existence of underground workings has been suggested by the find of a grooved stone hammer by Jenkins some ten years ago (Pickin

1990; Timberlake 1990d). According to Evans (Davies 1939) 'many stone hammers were formerly found underground', however, the existence of early underground mining worked by stone tools is not supported by earlier literary evidence. Ancient mines worked by cobblestones were described by Sir Christopher Sykes in 1796 as 'old shafts or drifts' (cited by Briggs 1976) which would suggest relatively superficial working. This is confirmed by Stanley (1873) who stated that ancient workings, containing cobblestones and charcoal, were mostly confined to the surface and that they did not appear to be worked to any depth. Pennant (1778, vol. 3, 58) described trench-like workings, presumably associated with the charcoal he mentions, occurring at several locations. It is probable that these were confined to the mineralized veins on the north side of the Mountain which were noted for their drainage problems (Greenly 1919, 825).

Spargo (1870) reported that cobble tools were still to be found in the ancient workings at Great Cwmsymlog in Cardiganshire. The workings were described as follows: 'The holes were dug along the veins a few fathoms, and at very shallow depths'.

Similar ancient open workings were described by Lewis Morris in 1747 for Twll y Mwyn (Bick & Davies 1994, 37): 'an old open rake was lately open'd, and in that p [*sic*], not above 9 yards in depth'. This too contained cobble hammers. Hughes (1981a) claims that stone hammers were still being found at Cwm Darren (which then embraced Twll y Mwyn) when the mine reached depths of 300 feet (91 metres) in 1852. It would seem difficult to conceive that possible prehistoric workings could reach such depths, especially when Lewis Morris noted that: 'it bore the expense of working where there is such a vast feed of water' (Bick & Davies 1994, 37). One of the Darren spades exhibited at the annual meeting of the Cambrian Archaeological Society in 1859 (Anon 1859), however, is apparently described as being found alongside stone tools in an old working at a depth of 70 feet (21 metres).

Present fieldwork and documentary evidence indicates that the majority of possible and confirmed prehistoric mines were irregular in form and relatively shallow in depth. The workings, varying in form with the local geology of each site, are undeveloped and take the form of pits, shafts, and drifts or rakes. The copper mines of Great Orme, however, are the exception. Bulk extraction there has been achieved by surface opencasting and trenching, and possible underground stoping although the main form of underground working is that of tunnelling. Nevertheless, these workings are still characteristically primitive and undeveloped compared to later historical workings. These exceptional conditions have been created by the local geology of the Great Orme described in section 4.1.2.

2.7.3 Fire-setting and ventilation

It is generally accepted that, where the rock was relatively soft, stone hammers could have been used directly (Craddock 1989). Where the rock was hard, however, the mine face would have first been subjected to heat treatment by lighting wood fires against it, a technique known as fire-setting. It has been suggested that if wood was scarce, charcoal may have been used instead. Historically, there is evidence for charcoal being mixed in with the wood in this situation and that other substitutes, such as horse bone, were even used (Hooson 1747).

Fire-set workings are very distinctive and readily differentiated from those worked by metal tooling or gunpowder as their profiles are smooth and rounded. Extensive tooling after fire-setting, however, may remove this feature (Willies 1994). The rounded form is produced by an exfoliating fracture mechanism of the rock surface due to expansion on heat treatment. The platy rock fragments so produced are jagged and are generally 1 to 5cm in thickness. In cross-section they are frequently dished and tapered to a sharp edge (Blackwelder 1927; Emery 1944). The resulting mine spoil, a mixture of this rock debris and charcoal, is readily distinguished from that produced solely by metal-tooling or blasting.

Fire-setting has certainly been employed at the Bronze Age mine sites, so far identified, in Wales and south-west Ireland. Early reporters identified ancient tip workings by the presence of charcoal in association with stone tools. The presence of fire-setting evidence alone cannot be used as an indicator to the antiquity of a mine working since this practice continued in use in some regions until the eighteenth or even nineteenth century, when it was succeeded by gunpowder blasting.

The effectiveness of fire-setting and stone tooling, for surface working, has been tested experimentally by a number of fieldworkers in recent years (Pickin & Timberlake 1988; Timberlake 1990b; Lewis 1990b; Crew 1990; O'Brien 1994, 167-172). Attempts have been made to quantify the ratio of wood consumed to the amount of rock removed. These figures are largely a reflection of the hardness of the worked rock. O'Brien estimated that the extraction of rock from Mine 3 at Mount Gabriel would have taken in the order of 100-200 fire-settings requiring 138-509 tons of wood. All the studies found that the maximum heat penetration of the rock face occurred immediately above the fire, resulting in a hollow 30 to 40 cm above the ground. Attempts have been made to lower this level of penetration, by different arrangements of the wood stack, using charcoal as fuel, and containing the fire in loosely stacked rocks (Lewis 1990b). For prehistoric workings, the only report of hearth-like structures has been made for Engine Vein at Alderley Edge. Roeder and Graves (1905) described these as 'rude fireplaces close to the rock-wall' of stacked blocks of 'calcined lead ore'. There is some doubt, however, as to whether these are from fire-setting as this treatment may not have been necessary as the sandstone host rock is relatively soft.

The problem of controlling the direction of the heat, as experienced during the course of these experiments, is documented historically. For example, Collins (1892) noted that this constant tendency to slope upwards was a problem experienced when driving drainage levels at the Kongsberg silver mines in Norway. Although this was partly alleviated by a better arrangement of the wood stack, (described in more detail by Manès in 1824 (cited by Penhallurick 1986, 73) for the tin mines of Saxony), the miners sometimes had to resort to blasting in order to remove the 'sole'. A way of working right down to the sole by fire-setting, described by the Derbyshire miner Hooson (1747), was to cut a slit to contain the fire known as a 'sticking'. Contemporary accounts described techniques of covering the fire with heavy baulks of wood, building stone ducts and constructing flues out of the wood stack as means to concentrate the heat of the fire on the floor (Willies 1994). This evidence suggests that the method of working by declined adits, proposed by Zschocke and Preuschen (1932) for the LBA mines of the Austrian Alps would have been difficult and only employed where the geological structure of the ore deposit demanded its use, for example at Mount Gabriel. Fire-setting can certainly be used to sink vertical shafts (Craddock 1992; Willies 1994), but progress in this direction is considerably slower. It is used to best effect with overhand stoping.

The practice of dousing or quenching is first described with vinegar, not water, by the classical writer Pliny (23-79 AD). It has been proposed that the reference to vinegar was copied from Livy's account of Hannibal crossing the Alps. Although the reference to vinegar has been interpreted as either a corruption of the word 'ascia', meaning axe, or an old wive's tale, the picture is complicated by an early Chinese reference to the same practice (Craddock 1992). Furthermore, it has been claimed that recent experiments have shown that a variety of rocks may disintegrate more readily when doused with dilute vinegar than with water (Shepherd 1992). The absence of this practice from contemporary descriptions, however, except in reference to Pliny, does not lend support to its use.

Some miners obviously believed that the explosive noises resulting from dousing indicated that it contributed to the shattering of the rock (e.g. Hooson 1747). However, quenching is not described by many mining handbooks, including Agricola's celebrated handbook on mining 'De Re Metallica', and recent fire-setting experiments have shown it to be ineffectual in further shattering the rock (Timberlake 1990b; O'Brien 1994, 167). It would appear that quenching served primarily to extinguish the fire and cool the rock so that tooling could proceed.

One of the recent fire-setting studies showed that vein quartz was more effectively cracked than the country rock of shale (Crew 1990). Two mechanisms in particular are responsible for this enhanced fracture behaviour in quartz. Changes in crystalline form experienced during heating and cooling through 250°C and 575°C, due to differences in thermal expansion coefficients, results in grain boundary or intragranular fracturing (Willies 1992). The deformation of fluid inclusions, a phenomenon known as decrepitation, which results in microcracks, occurs at a minimum temperature ranging from 260 - 420°C. This is most dramatic when inclusions are heated through the α/ß quartz inversion at 573°C, as this results in mass decrepitation due to the mechanical instability in the quartz crystal (Bodnar *et al.* 1989). Other physical and chemical processes involved in this heat induced fracture process are discussed in detail by Willies (1994).

Fire-setting would, undoubtedly, have had beneficial effects for subsequent ore processing by improving comminution and, in the case of primary ores, possibly helping to roast the ore.

The smoke and noxious fumes produced during fire-setting, particularly in confined underground workings, meant that this practice had to be carefully controlled. Historical references suggest that fires would normally be lit at the end of the day and left to burn out over night or the weekend (Hunt 1887). In many mining districts fire-setting was regulated by charter and mining law. It would appear from Tonkin's account of fire-setting in Cornwall, written in 1733, that attempts made to work below the level of fire-setting often resulted in fatalities as sudden changes in wind direction would drive the smoke down (cited by

Penhallurick 1986, 71). Proper ventilation systems, which allowed fire-setting to be employed without evacuating the working, were not developed until the nineteenth century. There is no evidence to suggest that sophisticated stoping and ventilation systems, such as those proposed for the LBA copper mines of the Mitterberg in Austria (Zschocke and Preuschen 1932), pre-date the post-Medieval period.

2.7.4 Tooling

Prodigious numbers of stone tools and tool fragments are found on Bronze Age mine sites. The recovery of bone tools, worked wood and bronze fragments during recent excavations would suggest that mining tool kits may have been composed of an assortment of materials and forms, but these survive only in exceptional circumstances.

2.7.4.1 Stone

Stone hammers were used as rock-breaking tools in conjunction with fire-setting. These tools are sometimes described as mauls. Recent experiments have proved these tools to be very effective (Pickin & Timberlake 1988; Timberlake 1990b; Lewis 1990b; Crew 1990). There is also some evidence to suggest that stone tools may have been used to hammer bone points (Dutton 1990) and even bronze implements (Lewis 1990a).

All the stone tools are derived from natural sediments, such as beaches, rivers/streams, till and soil, so they are consistently found to be rounded by weathering and erosion. This means that they are distinctive and highly visible in mine spoil contexts since such cobbles, for the most part, do not naturally occur at these sites. In many instances, the rock types of the stone tools are foreign to the mine site either because suitable cobbles do not occur naturally in the vicinity of the mine, or, the cobbles have been derived from glacial and re-worked glacial deposits containing sediments originating from outside the area. In some cases, for example at Mount Gabriel, cobbles of the identical rock type to the host rock of the mine were employed because no other material was locally available. Although these stones were not shaped, they can, on occasions, be modified to facilitate hafting. This may take the form of edge notches, small patches of pounding or even a continuous waisting, known as a 'groove', around the midriff of the cobble. The latter form are associated with the Alderley Edge mines, but occur only rarely for the other sites in Wales. It has been suggested that the form of modification is likely to be linked to the geology and lithology of the ore deposit and cobble source (Pickin 1990).

The distinctive rounded form of fire-set mine workings, described above, is characteristic of both stone and metal tooling. Although tool marks, in general, can be difficult to identify in such workings, stone tool marks have been clearly recognized at a number of mines where the rock was of sufficient softness that it could be tooled directly without recourse to fire-setting. Probably the best example is found at Timna in Israel, illustrated by Craddock (1986; 1989), where the stone tool marks consist of diffuse pecking or dimples. Similar workings survive at Alderley Edge in Cheshire and here they are contrasted with metal tooled and blasted workings which have cut and partly destroyed the earlier pits (Gale 1986; 1989). The surfaces of these primitive pits are rounded and smoothed, much like fire-set workings. Identical marks are clearly visible in the roof of the small gallery working exposed in the wall of the opencast at Copa Hill, Cwmystwyth (Timberlake 1990a; 1990c).

Apart from cobblestone tools, there are only a small number of reports of other stone tool finds, for example, polished axes. However, these cannot be proved to be connected with early mining. Peake (1937), reporting second hand, mentioned that a conically perforated stone hammer was recovered from the Trecastell mine in Caernarfonshire (Gwynedd), and then lost.[3] A perforated battle-axe find from Foxdale Mine, Isle of Man, has also been reported (Pickin and Worthington 1989)[4] but there are no details concerning its discovery (see section 2.5). Finally, a number of perforated axe-hammers have been recovered from Alderley Edge (Clough & Cummins 1988, 219) but again there is no evidence to suggest that these are related to the early mining activity associated with stone hammers.

From an early date, there have always been suggestions that modified stone hammers were hafted by withies, twigs, sinews and rope. Although a handle of twisted hazel has been recovered from the excavations of Mine 3 at Mount Gabriel (O'Brien 1994, 151), no examples of hammers still retaining their handles have been recovered except for a single find made last century which is now lost. This discovery was made at Parc, or Park Lodge, copper mine near Machynlleth, known as Ogof Wyddon, as a result of prospection activity in 1856.[5] Barnwell (1870) described the find as consisting of 'a boulder stone converted into a hammer, the handle of which being a withe twisted around it'. No further details are known.

2.7.4.2 Bone

The recovery of bone will, obviously, depend on the general environmental conditions of each site, and, even particular sections within a site. In most instances the mine environment will not be favourable due to acidic ground water resulting from sulfide mineralization. The limestone environment at Great Orme, however, is slightly alkaline and, as a consequence, bone has been preserved. Approximately 9000 fragments of bone have so far been recovered (Dutton *et al.* 1994). A preliminary study of the assemblages recovered by James and later surface excavations by the Gwynedd Archaeological Trust in 1988 and 1989 showed that only between two and 5 percent of material was modified for, or during, use as tools. The assemblages are dominated by the bones of cattle and other large ungulates, and that other identified species include wild pig, sheep, goat and red deer. It is apparent that particular bone types were selected as tools. Long-bones, particularly tibia, were employed as points, becoming characteristically tapered and rounded through use. Dutton *et al.* (1994) described some of these as being eroded at their broadest ends, suggesting that this may be percussion damage from hammering with a stone tool. Rib bones represent another class of tools which use-wear suggests were used in a slicing action. Only a few fragments of antler have been recorded and these were excavated at the surface (Lewis 1990a).

Several hundred bone fragments have been recorded in underground contexts (Lewis 1990a). Bone tool marks have been identified underground where soft, mineral bearing, shale horizons, and rotted dolomite have been worked. Three radiocarbon dates have been derived from bone (Lewis pers. comm.) which correspond to the results obtained from charcoal samples.

For the remainder of the Welsh sites, the ground conditions are generally too acidic for the preservation of bone. The only other bone material to have been recovered are two fragmentary pieces of red deer antler excavated from the tips at Copa Hill (Timberlake & Switsur 1988). There is a single antiquarian report of an antler find made at Nantyreira in *circa* 1859 (Anon 1860). This is described as; 'a portion of a stag's horn fashioned so as to be suited for the handle of some implement'. This was recovered from the bottom of the old workings at a depth of about 60 feet, along with an iron pick-axe with handle and a 'ponderous ball of stone'. These are now lost. The most probable explanation for this odd mixture of finds, is that earlier material, cleared out by historic working and tipped along the margins of the trench working, had been washed back in.

Fire-setting experiments have demonstrated that antler picks form an effective tool for prising out loose fire-shattered rock fragments (Timberlake 1990b; Lewis 1990b).

2.7.4.3 Wood

An oaken spade recovered from the surface workings at Brynlow, Alderley Edge, in the nineteenth century (Sainter 1878), has been radiocarbon dated to the Middle Bronze Age. A short-handled shovel of alder has also been recovered from Bronze Age contexts during excavations at Mount Gabriel as part of a large assemblage of wood preserved in the waterlogged sediments contained within Mine 3. Other pieces of worked wood included two fragments of at least other shovels, a hazel pick, a wedge and five whittled objects which were thought to have been wedges and pry sticks used for prising out loose rock fragments produced by fire-setting (O'Brien 1990). Such implements, however, when tested in a fire-setting experiment were found to be ineffectual (Timberlake 1990b).

A total of five oaken spades, apparently found in association with stone implements, were recovered from the upper workings of Darren mine between 1858 and 1865 (Anon 1859, 1861, 1866; Williams 1866). These were displayed, on a number of occasions, at the annual meetings of the Cambrian Archaeological Society. Unfortunately, none of these have survived but the Ceredigion Museum, Aberystwyth, does hold a single replica (Hughes 1990).

2.7.4.4 Metal

Antiquarian reports of discoveries of ancient mine workings have, on a number of occasions, described stone and metal tools (most usually of iron) being found together (Hunter 1884; Roeder & Graves 1905; Anon 1860; Barnwell 1870). Unsubstantiated reports of stone and metal tool associations, such as those made for Parc Lodge and Nantyreira, might reflect one of the following conditions: 1) a mixing of deposits as a result of reworking, 2) finds derived from separate contexts which were then taken away together, and 3) the contamination of more recent workings by the collapse or in-wash of older material. At Alderley Edge the iron object recovered from the early mining pits at Engine Vein, and originally described as a pick, has been identified as the remains of a nineteenth century boring rod (Warrington 1981).

The discovery of metal, in the form of bronze, has only been demonstrated to have been found in strictly prehistoric contexts at the Great Orme. Stanley (1850) reported that bronze objects had been being recovered from both discoveries of 'old-man' workings at Great Orme in the nineteenth century. On the first occasion, *circa* 1832, 'two mining implements, or picks, of bronze, were found, one about three inches in length' (Stanley 1850). The smaller of the two objects, measuring 3.2 by 2.0cm, is held by the British Museum (Smith 1989). In 1849 a further metal object, described in shape as a 'button' measuring 3.2cm in diameter, was discovered (Stanley 1850) and this is also held by the British Museum. This has recently been identified as brass (Craddock & Hook 1991 cited by Dutton *et al.* 1994). Recent excavations have recovered nearly eighty small fragments of bronze from a single underground spoil context (Lewis 1994), charcoal from which has been radiocarbon dated as 1410 to 1070 cal BC (Lewis 1990a). It was initially suggested that these fragments may be burr from a bronze chisel or wedge (Lewis 1990a; Jenkins & Lewis 1991) but this is now thought to be unlikely in view of their number (Lewis 1994). Although it has been claimed that copper hammers have been found (Wheeler 1926), no complete copper-based artefacts have yet been recovered. Parallels may perhaps be drawn to finds made in the Bronze Age mine workings of the Mitterberg region (Andree 1922; Zschocke and Preuschen 1932).

2.7.5 Propping

Evidence supporting the use of timber for propping is inconclusive. Limited or small workings, such as the inclined tunnel workings of Mount Gabriel and the tight tunnel workings at Great Orme, would not have required propping. Nevertheless, O'Brien (1990) suggests that a number of short timber baulks, recovered within the excavations of Mine 3, may have been props. These were not, however, found *in situ*.

On the other hand, timbering may have been thought to be necessary when stoping or opencasting/trenching at depth, by providing a means of shoring waste, protecting from activity above and for forming false floors for working the roof of a stope. At Copa Hill, pick-cut stemple holes, one of which contained traces of wood, in the wall of the opencast workings at a depth of 4-5m are probably related to a Medieval shaft feature (Timberlake 1991b; Timberlake & Mighall 1992).

At Great Orme, the conditions for the preservation of wooden artefacts are unfavourable, but even so there is no evidence of any rock cut features capable of containing props or boards either in the surface trenching or in the large stope, the 'Flat Stope', which is thought to be predominantly prehistoric. Evidence for limited revetting of prehistoric pack by drystone walling, however, has been uncovered within the opencast adjacent to Vivian's Shaft (Dutton 1990), thereby securing access via three short shafts into the Flat Stope (Hammond pers. comm.), and within a narrow passage leading off the north-west side of the opencast (David 1993). This is built up to the roof of the passage but it is not clear whether this was intended to act as a support.

Richardson (1974) includes 'old timbers' in his description of the ancient copper workings at Alderley Edge. Although timber has been recorded underground in the historic workings, there is no original reference to timber finds in association with stone tools or the surface pitting.

2.7.6 Lighting

At Mount Gabriel, from the excavations made within Mine 3, large quantities of charred pine chips were recovered which O'Brien (1990; 1994, 158f) suggested may be remnants of torches or kindling. Many of the workings at this site, however, are relatively shallow so that artificial lighting would have been largely unnecessary.

For the British sites, lighting would have been necessary at Great Orme. It has been suggested that a recent discovery of burnt brushwood or possibly straws, measuring up to 35cm in length, found on ledges and in shallow alcoves within prehistoric contexts may represent spills from a light source (Lewis in press). Furthermore, Dutton *et al.* (1994) observed that in some areas of the prehistoric workings there are very localized sooty stains and speculates that these may further evidence of lighting. More traditional forms of evidence, such as fat or resin residues, bundles of twigs, lamp niches or clay pads, have yet to be discovered.

2.7.7 Drainage

Drainage at the Great Orme copper mines would have been superfluous even at the deepest prehistoric workings, some 60 metres, due to the porous nature of dolomitized limestone. The mine workings at Mount Gabriel, Cwmystwyth and Alderley Edge, on the other hand, are essentially extended surface operations which, as a consequence, lack underground development. It is, therefore, inappropriate to consider any of these mining operations in terms of drainage features such as cross-cuts and adits. O'Brien (1990, 273) suggested that the length of the Mount Gabriel workings was limited by 'various operational difficulties posed by increasing depth, the most serious of these being flooding', in addition to lower ore returns.

From the floor of the Copa Hill opencast, two wooden launders made of split oak trunks were uncovered during excavations in 1993 (Timberlake 1993). One of these is apparently *in situ* and a length of over two metres has been exposed at the entrance to the mine lying on the rock cut floor. This has been radiocarbon dated to the EBA (table 2.1). Timberlake suggested that it was used to drain the mine working (Timberlake 1994).

No material evidence for bailing, such as remains of buckets or other containers, has yet been recovered from the excavations at either Mount Gabriel or Cwmystwyth.

2.7.8 Haulage

This can be considered in two parts: containers for conveying ore and methods of drawing these to the surface. There are records of basket fragments being found amongst ancient mining remains at Esgairmwyn by Morris in 1756 (Timberlake pers. comm.). No material evidence has been recovered more recently which is, perhaps, unsurprising as finds from other extensive European mining districts are rare, being confined to mines of a later period with exceptional preservation conditions (Davies 1935). There is also no evidence for winding either in material form or as rock-cut features such as rope marks or sockets for the seating of a windlass.

2.7.9 Access

There is no evidence to suggest that shaft or adit type workings were used solely to access mineralized ground. Shallow shaft-like workings which exist at the Great Orme appear to be entirely extractive in nature (Dutton *et al.* 1994).

Artefacts and features have been linked to the prehistoric access of the excavated mine working at Mount Gabriel. Here, foot notches have been identified at the entrance sill and a number of large, split oak plants, some with tread wear, have been interpreted as loose step-planks (O'Brien 1994, 152).

2.8 Ore-processing

Whereas cobblestone hammers are known to have been employed as mining tools only during the Bronze Age, stone was used for mineral dressing up until the post-Medieval period. The types of ore-dressing tools recovered in Mid-Wales are discussed by Thorburn (1990). It should be noted that most of these were still utilized cobble and boulder stones. Hand-held ore-dressing stone tools are not reported from Wales for this period.

In prehistoric contexts it has been recognized that some stone hammers employed as mining tools would also have had a secondary role in dressing the ore, as evidenced by depressions or 'cup marks' (Pickin 1988, 1990). O'Brien (1990), referring to Mount Gabriel, has described this technique as 'block-on-block' crushing. Here, an area of associated activity, described as a 'mining camp' was uncovered by excavations to the periphery of the mine tip. Although no specific ore processing tools were recovered, a slab structure and a dense concentration of broken stone tools were seen to be evidence of secondary ore-processing. In addition, a posthole structure and a water trough were identified but it seems highly unlikely that water treatment would have been used to perform gravity concentration of the ore (O'Brien 1990; O'Brien et al 1990; O'Brien 1994, 102-116). No similar structures have yet been discovered by excavations at the sites in Wales.

Many of the ore-dressing stones found on prehistoric mine sites may be attributable to later mining activity (see sections 6.2 & 6.3). Solitary examples of small mortars, described as hand mortars, have now been recorded at a number of sites (Thorburn 1990; Timberlake pers. comm.). It is difficult to prove that these are exclusively associated with prehistoric mining activity because all of these have been recovered from the surface. At Great Orme, a number of these examples have now been found, together with a collection of small spherical pounders, the latter probably having been used in conjunction with the former.

These have been found, however, in nineteenth century surface spoil and tip of mixed age (Dutton 1990).

No grinding stones have been recovered from these sites. Although Davies (1938; 1939; 1946; 1948) reported that stone hammers were also used as querns and mullers no such material has been reported during more recent fieldwork.

Notes

[1] Isle of Man Examiner, 8 Sept. 1906.

[2] The Dawkins Collection, Manchester Museum. 1874 notebook.

[3] Davies manuscript, Trecastell (undated).

[4] *vide* 1.

[5] Eddowes Shrewsbury Journal, 14 May 1856.

CHAPTER THREE

Stone Tool Studies in Relation to Prehistoric Metal Mining

3.1 Previous work

There have been only a small number of studies concerning stone tools from metal mining sites and these have arisen from recent fieldwork in the British Isles and Serbia. These consist of regional surveys of tool types and site-based studies. Most of this work has been concerned with classifying tools into types on the basis of haft modification and cobble shape. These types have, in some cases, been claimed to reflect differences in tool use or function. There are also a small number of site-based studies (Dawkins 1875; Roeder 1901; Dutton *et al.* 1994) which, because they are essentially descriptive, have not been included in this discussion. Studies of tool form in relation to the geological structure of individual mines, which, for example, has been applied to flint mining (Borkowski *et al.* 1991), have not been possible because of the geological homogeneity of most deposits and the rare survival of mine workings and associated spoil.

Stone hammers from mine sites have become called 'grooved hammerstones' since a number of European sites are characterized by mauls modified to accommodate hafting by means of a shallow channel around the central body of the stone. This term has often been rather loosely used to describe whole assemblages regardless of the form, or even absence, of haft modification. Groove-type modification for hammers from Britain was known to be limited to one site in particular, i.e. Alderley Edge in Cheshire. A survey of sites in England and Wales (Pickin 1988; 1990) showed that other less developed forms of modification were widespread. Pickin (1990) divided hammers into six classes on the basis of haft modification, suggesting that the degree of working may be explained by local geology and lithology.

Site-based studies have been undertaken for material from Copa Hill, Cwmystwyth in Wales (Timberlake 1990c), Mount Gabriel in southwest Ireland (O'Brien 1994), and Rudna Glava (Jovanović 1982) and Rudnik Mountain in Serbia (Bogosavljević 1988). At Copa Hill, some 350 stone hammers exposed at surface of the tips have been recorded (Timberlake 1990c). These were classified into thirteen arbitrary types on the basis of modification, stone size and shape, and the presence and type of end use. Some of these types were thought to reflect different functions or methods of employment although these appeared to be unrelated to size and shape. It was recognized that hammers were also used for crushing ore. It was observed that the hammers were, in general, much more rounded than cobbles from local sources and that considerable difficulty was experienced when trying to select comparable stones for use as mauls in fire-setting experiments (Timberlake pers. comm.).

Excavations at Mount Gabriel recovered a considerable number of stone hammers and tool fragments (over 2500) from mine, spoil and associated contexts (O'Brien 1994, 117-135). Analysis of this material involved the study of lithology, size, cobble shape (sphericity), haft modification and use-wear. Use-wear classes were constructed by examining breakage in conjunction with the degree of use. The pattern of use-wear between contexts was thought to reflect differences between rock extraction and ore-dressing. A high proportion (40%) of the assemblage was discarded in a 'serviceable' state although very few (2%) unused cobbles were found. It was concluded that hammers showed no functional differentiation and that modified hammers were identical in form to unmodified ones although grooved (or 'rilled' as they are described) hammers and hammers modified with deeply notched edges were shown to be more spherical. The form and size of the material was also studied in relation to its source from the beach about four kilometres away.

The two Serbian studies have resulted from fieldwork, involving the Institute for Archaeology, Belgrade, at Rudna Glava and Rudnik Mountain. From excavations at the former site over 200 stone hammers were recovered. Jovanović (1976; 1978; 1979; 1980) proposed that size and natural shape varieties could be identified which would suggest tool specialization demanded by different working conditions in both mining and processing. Stanojević (1982), however, in presenting the final classification, admitted that there was a great variation in the natural form of the mauls. The fact that this would appear to be a visually constructed classification would suggest that the shape types do not form real groups.

A similar system of classification was used in the study of stone mauls from the copper mine of Mali Šturac, Rudnik Mountain (Bogosavljević 1988). As well as natural shape types, three classes of groove modification, based on an index of groove depth and width, and three use-damage classes were employed. Bogosavljević suggested that, where the hammers had been intensely worked, use-wear patterns could be characterized by the shape of the resulting facet or the form of flaking/breakage.

Stone hammers have been used experimentally in a number of recent fire-setting studies in Britain, both as hand held and hafted tools. Hafting was achieved by using rope slings, withies and paired hazel hafts (Pickin and Timberlake 1988; Craddock 1990; 1994). There have been no attempts to compare breakage or use-wear patterns arising as a result of using different methods of hafting to the original stone tool assemblage, but, in any case, only a small number of such replicative stone hammers have been generated.

3.2 Discussion

Although previous studies of stone hammers indicated that the form and degree of haft modification is related to geology of the mine site, there have been no attempts to investigate this relationship. Suggestions that hammers fall into shape and size categories which represent differences in function or specialization have not been rigorously tested. Moreover, the Mount Gabriel study suggested quite the opposite and that even modified hammers were identical in form to unmodified ones. Nevertheless, there is some evidence to suggest that particular cobble forms were selected at source.

A number of workers have noted the practical difficulties involved in identifying ore-dressing use-wear on stone mauls and distinguishing between haft modification and use-wear. In the main, hammers joint-used or reused for ore-dressing, or used in other ways, have not been identified. These studies have also been concerned entirely with end-worked hammers and other tool types, such as edge-worked hammers, and reused tool fragments have not been included. In addition, most studies have concentrated on complete or near complete material and this may not be representative of properties of the whole assemblage.

3.3 Further work

A number of areas of investigation for further work can be identified:

1) whether functional specialization can be identified within stone hammer site assemblages by cobble morphometry and use-wear analysis.

2) whether the proportion of unmodified to modified stone hammers and the degree of modification is related to local extraction conditions.

3) the methods of ore-dressing.

4) evidence for other activities related or unrelated to mining operations, e.g. wood dressing tools, whetstones for sharpening metal tools, other tools associated with domestic activity.

5) qualities sought for in the selection of cobbles for use as mining tools.

6) the organization of ore extraction in the Bronze Age by studying tool consumption and use.

As each site will have a unique set of working conditions, owing to differences in the local geology of the mineralized deposit as well as cobblestone sources, the areas of investigation outlined above are mostly effectively tackled by studying a number of site assemblages.

CHAPTER FOUR

Background to the Mine Sites and Material under Study

Material from five sites in England and Wales has been selected for study, namely Alderley Edge, Great Orme, Copa Hill in Cwmystwyth, Parys Mountain and Nantyreira. In addition to being the only metal mines in Great Britain where mining activity has so far been securely dated to the Bronze Age, they are the only sites from which the available collections of stone tools are large enough for this type of study. The Welsh site assemblages have been created mainly as a result of recent fieldwork aimed at identifying prehistoric mining activity. The assemblages consist, in the main, of material recovered by excavation and, to a lesser extent, by surface collection. Surface finds of stone tools only occur in sufficient profusion for recording in the field to be undertaken at Copa Hill.

This chapter describes the geology, history and archaeology of the sites, and explains the contexts of the stone tools available for study.

4.1 The Great Orme

4.1.1 Site description

The Great Ormes Head is an isolated promontory of limestone, rising to 207m OD, that outcrops along the coast of North Wales. The mine workings extended from St. Tudno's Church on the north side, virtually due south for one kilometre to Maes-y-facrell. Underground surveying has recorded prehistoric workings extending over a distance of 240m from Roman Shaft at Bryniau Poethion south to Vivian's Shaft which are estimated to cover an area of 24,000 square metres (Lewis 1993; in press). Craddock (1995, 60) has described the mine as one of the largest in Europe. Extensive prehistoric workings have been exposed at surface by machining on the Central Vein around Vivian's Shaft, Pyllau (plate 1). The form

Plate 1. Prehistoric copper mine workings exposed at surface in the area of Vivian's Shaft, the Great Orme.

of these workings is described in section 2.7.2. The site has been developed by the Great Orme Mine Company and a visitors' centre was opened to the public in 1991. Underground workings have been made accessible from this point.

The workings and valley side have been substantially infilled by seventeenth to nineteenth century mine spoil. The original land surface probably consisted of a series of stepped scars. The lodes were worked from the surface by trenching and opencasting, and at depth by limited stoping. Minor parallel fissures and caunter lodes were initially worked by trenching and then by driving tunnel-like passages from the mine and scarp faces. Many examples of these workings have now been exposed at surface.

4.1.2 Geology and ore mineralogy

The Great Ormes Head is composed of Lower Carboniferous (Dinantian) limestone folded into a gentle syncline. The limestone strata consists of alternating massive and rubbly beds interbedded by mudstones (Warren *et al.* 1984, 113). The predominant fault trends are approximately north/south and parallel to the strike, i.e. east/west to southeast/northwest (fig. 4.1). These are high-angle fractures with small displacements (Warren *et al.* 1984, 144).

The main lodes consist of three or four multiple parallel fault systems trending north/south, forming a mineralized belt 100m across which outcrops for a distance of 750m. This zone contains numerous, closely spaced, mineralized minor north/south fissures and subsidiary east/west joints. These fractures are almost vertical and show little displacement. The lodes were found to be most productive where they were intersected by cross veins (Davies 1881, 138). The only productive northwest/southeast lode, worked by the Ty Gwyn mine, is located on the east side of the Great Ormes Head. There is no evidence of prehistoric mining in this area.

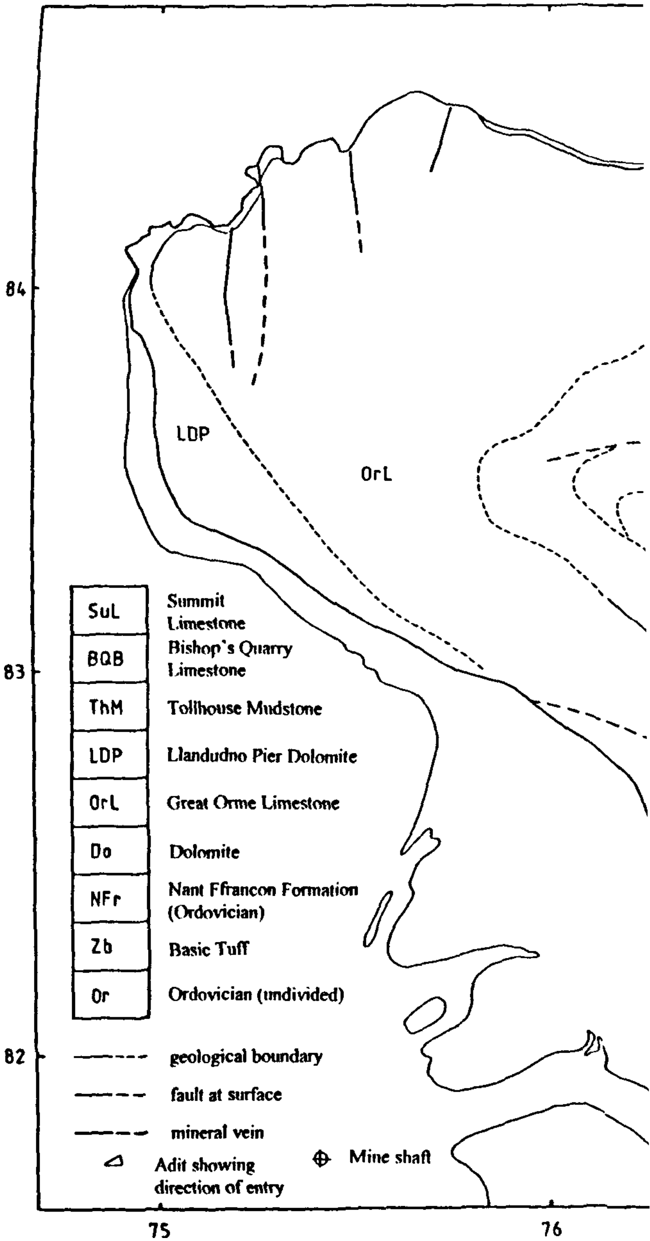
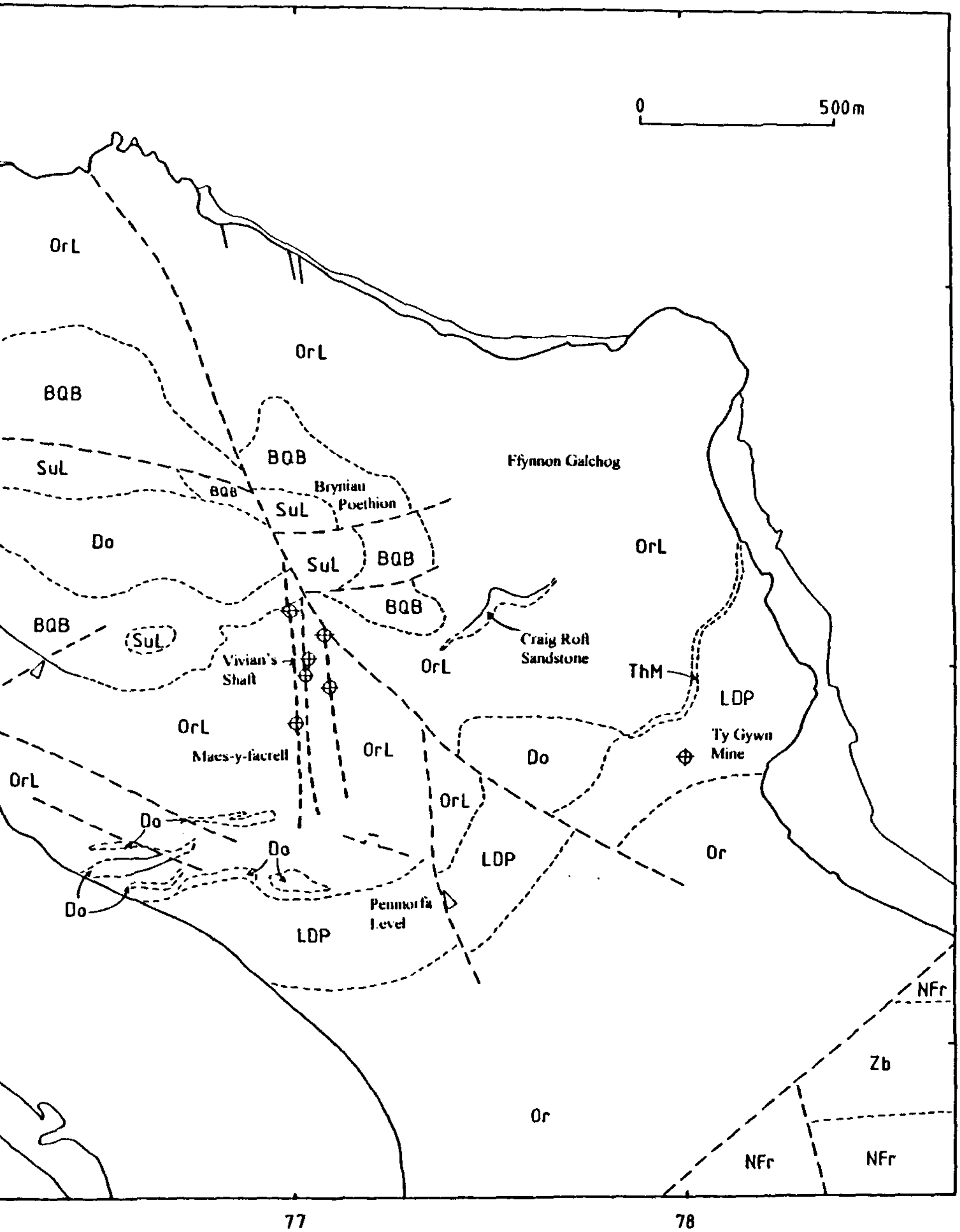


Figure 4.1 The geology (solid) of the Great Ormes Head.



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BQB
SuL
Craig Roft
Sandstone
Vivian's
Shaft
OrL
ThM
LDP
OrL
Maes-y-facrell
OrL
Ty Gywn
Mine
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OrL
OrL
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Or
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Penmorfa
Level
LDP
NFr
Zb
Or
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NFr
77
78

The mineralization is associated with secondary dolomitization, being confined to certain beds beneath mudstone/shale beds traversed by faults (Dewey & Eastwood 1925, 51; Morton 1898; Lewis in press). Dolomitization results in shrinkage and the formation of small cavities along fissures (Dutton *et al.* 1994). These are drusy in nature, containing crystals of dolomite and calcite (Neaverson 1937). The mineralization occurs within these vugs and along faults, joints and bedding planes, and within thin shale and clay horizons interbedding the limestone. The mineralization has recently been studies in detail by Ixer (n.d.). The main source of ore in the Bronze Age was from the decomposed ore-bearing dolomite which formed a soft granular deposit comprised of crystals of dolomite, ankerite and calcite (Dutton *et al.* 1994; Lewis; 1994; in press). This rotting effect is most pronounced at surface and would have made the extraction of ore minerals a relatively easy task. This decomposition has been attributed to a process of supergene dedolomitization which partly converted and redistributed copper from sulfide minerals to carbonates and oxides (Lewis 1994; Ixer n.d.).

The primary ore consists of chalcopyrite which occurs as crystals coating the dolomite and as thin veins (1 to 2cm thick) contained within. This has been oxidized to goethite and malachite which infill vugs and fractures, and coat the chalcopyrite (Lewis in press). With depth these give way to chalcopyrite, although carbonate ores have been recorded to depths of 200m. Other oxidized products include trace amounts of azurite, cuprite, native copper and tenorite (Smith 1989, 9; Bevins 1994, 25; Dutton *et al.* 1994). Rare occurrences of secondary copper(II) arsenates and cobalt minerals, olivenite, linnaeite, clinoclase and erythrite are also known (Dutton *et al.* 1994; Bevins 1994, 25). Reports of copper sulphide minerals forming in zones of supergene enrichment include chalcocite, digenite, djurleite and the copper arsenic sulfide enargite (Bevins 1994). Small but profitable quantities of galena also occurred. The maximum depth of oxidation is unknown, although nineteenth century accounts suggest that the watertable was about 200 feet (61m) below the surface before the workings were drained by the Penmorfa Level.

The mudstone bands, which acted as mineralization traps, contain secondary minerals in the form of thin seams of malachite and jarosite, as well as small pellets (up to 1cm in diameter) of malachite and, more rarely, azurite. These deposits obviously extend beyond the mineralized faults; for exampled, one mudstone horizon accessible from Owen's Shaft, around one metre in thickness, covers an area of about 700 sq m.

The copper ore extracted in the nineteenth century was relatively high grade, yielding up to 34% copper (Smith 1989, 9).

The valley side of Pyllau is covered by a thin layer of boulder-clay up to several feet thick (Lucy 1873), which has now been exposed by the excavations around Vivian's Shaft. The mineral lodes would have been readily accessible to the early miner, however, as they would have outcropped in rock scars.

4.1.3 Mining history

The history of the mines has been described by Williams (1979), Bick (1985) and Smith (1989). The earliest written reference to mining is in the form of a lease issued in 1692 permitting mining at Maes-y-facrel. Mining had evidently been carried out before, however, since a lease drawn up two years later, for the neighbouring land at Pyllau, refers to old workings (Williams 1979, 17). The workings must have reached considerable depths because, in 1748, Lewis Morris mentioned that the abandoned workings were flooded (cited by Williams 1979, 17). The mine was active again in 1761 and by the end of the century it had become divided into two ventures which were to become known as the Old Mine and New Mine. Tourist accounts and regional guides suggest that mining operations in the late eighteenth and early nineteenth century were small-scale. The mines were most prosperous from the 1830s to 1850s but thereafter they rapidly declined. The Old Mine continued to be worked in a minor way into the 1870s.

The Ty Gwyn Mine, situated in the area now known as Happy Valley, opened in 1835. Although it was a particularly rich mine it was greatly troubled by water, since the workings extended under the sea, and this led to the mine's closure in 1853.

The total nineteenth century production for all three mines has been estimated to be about 50,000 tons of copper ore (Williams 1979, 47).

4.1.4 Archaeological background

When Stanley (1850) reported the discovery to the Archaeological Institute, in 1849, of old-man workings at Great Orme, he also described an earlier find made some eighteen years previously from which an antler and two small bronze objects were recovered. The latest discovery, at a depth of eighteen yards (sixteen and a half metres), consisted of a large cavern, 40 yards (36½ metres) in length which contained stone benches. The cavern also contained stone hammers, reported to weigh from one to fifty pounds, and large quantities of animal bones, some of which had been used as chisels (Gentleman's Magazine 1849, 32, 630; Stanley 1850; Hicklin 1863, 65). A further small bronze object was also recovered. The miners were said to have found these old workings very rich in ore as the 'old-man' was apparently unable to work the harder parts of the rock (Stanley 1850). The cavern was likewise reworked by blasting and its whereabouts soon lost.

Davies undertook fieldwork at Great Orme from 1937 to 1939 for the British Association for the Advancement of Science (Peake 1937, 1938, 1939; Davies 1948). Stone tools and sawn bone were recovered from mine spoil in the area of Bryniau Poestion south of Pyllau, but test trenching failed to yield ancient tip material. Attention was then switched to the south side of the Great Ormes Head, to a habitation site behind Gogarth Hotel on the

West Shore (SH 771 823), close to the mouth of the Penmorfa Adit. A number of small pottery fragments attributed to the 2nd/3rd century AD were recovered. Davies suggested that the site was a Roman mining settlement since he believed that Roman coin finds had been made in connection with the mine workings (Davies 1935, 157). On closer scrutiny, however, there is very little evidence to suggest Roman exploitation of the mines. It has been claimed that Roman coins were found by miners underground (Gardner 1908, 1958; see also Wheeler 1926, 77), however, as there is no corroboratory evidence these are best treated with suspicion. Gardner (1908, 1958) has even suggested that the two large Roman coin hoards made on the Little Ormes Head (Odgen 1909, 1915) are connected with the mines. A number of Roman coin finds have also been found on the Great Ormes Head (Dally 1915; Gardner 1958; Jones 1888) but these are unconnected with the mines.

From 1976 James explored and surveyed old workings under Bryniau Poethion (James 1988). Subsequent excavations in the mid-1980s of two mine passages at a depth of 30m, associated with charcoal and stone and bone tools, produced a radiocarbon date to the Middle Bronze Age (table 2.1).

Reclamation of the mine workings in the late 1980s involved the capping of shafts and the landscaping of mine spoil. It was also proposed to build a car park at Pyllau and, in order to assess the suitability of the site, an underground survey of the workings to a depth of 20m was undertaken. To make the Vivian shafthead safe, the spoil overburden was removed down to bedrock in 1988 and this was overseen, with some manual excavation, by the Gwynedd Archaeological Trust. On completion of the reclamation scheme, an application was made to develop the site into a mining heritage centre and, as a consequence, further excavations were undertaken in this area by the Trust in 1989. The Great Orme Mine Company was formed in 1990 and they then developed the site for public display. This involved the further removal of mine spoil by machining which exposed the prehistoric surface workings around

Vivian's Shaft and led to the construction of a walkway through a series of underground workings exposed at a depth of 15m in the rock face on the east side of the Shaft (fig. 4.2).

Manual excavations have continued at Vivian's Shaft since 1991, both at surface and underground, and further radiocarbon dates have been obtained (table 4.1). Dutton *et al.* (1994) estimates that as many as 900 stone tools have been uncovered up to 1992 and as many as 9000 of bone pieces, consisting of tool fragments and meal remains, have been recovered to date. The bone material recovered by the Trust in 1989, amounting to around 2,500 fragments, has been studied in detail (Dutton *et al.* 1994). Recent surface excavations have concentrated on an area of minor trench workings on the west side of Vivian's Shaft and workings leading off the north-west side of the main opencast (David 1993). There is some limited evidence to suggest prehistoric reworking close to surface and this has been linked to the extraction of harder chalcopyrite ores after the exhaustion of the softer, more accessible, malachite ores (Dutton *et al.* 1994). To date, nine radiocarbon dates have been published (table 2.1) spanning the period from later part of the Early Bronze Age to the Early Iron Age.

Three ore-processing sites are known on the Great Ormes Head and these are sited at springs. Considerable quantities of copper-bearing ore were apparently recovered from these in the nineteenth century. One of these sites, Ffynnon Galchog, yielding stone tool spalls and bone fragments, has been recently excavated (Lewis 1990d; 1994; in press) and a single radiocarbon date was obtained (Ambers pers. comm.) which gave an unexpected Dark Age date range (table 2.1).

4.1.5 Stone tool collections

A small number of stone tools from the 1849 discovery which found their way into private collections are now held by a number of municipal museums. The material recovered by

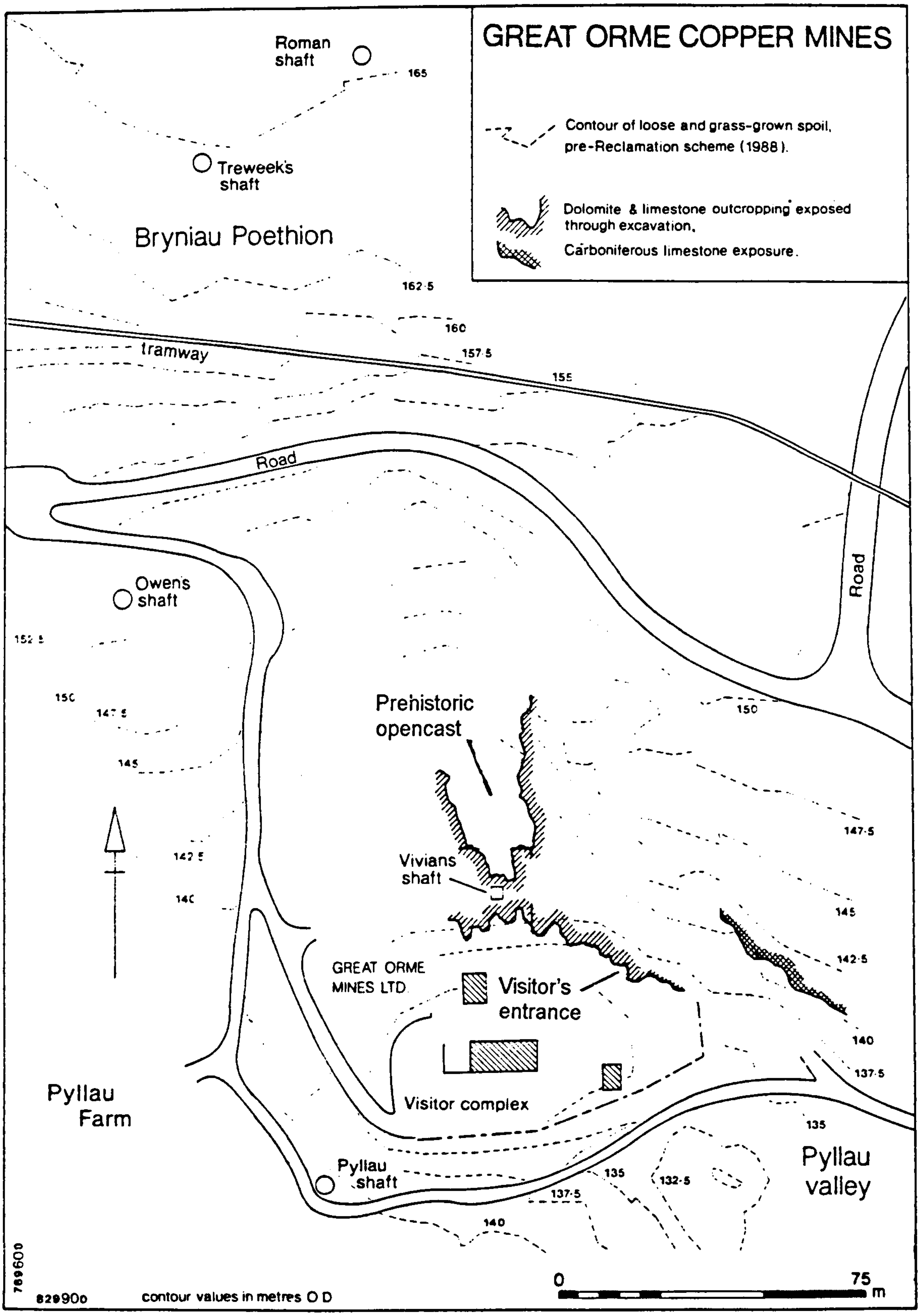


Figure 4.2 Plan of excavations around Vivian's Shaft, Pyllau Valley, the Great Orme (after Dutton *et al.* 1994).

Davies in 1937 (Peake 1937) has not been traced and the finds made in 1939 were mislaid during the war (Davies 1948). The bulk of the material available for this study was, therefore, made up of finds recovered during recent excavations. During the machining of both the shafthead and the mine workings, a watching-brief was kept and a large number of stone tools were recovered from modern and ancient tip material.

4.2 Copa Hill, Cwmystwyth

4.2.1 Site description

The Cwmystwyth Mines are situated on the north side of the River Ystwyth, 23 kilometres inland from Aberystwyth. The opencast associated with prehistoric working is located on the eastern margin of the mine where the Comet Lode outcrops in the scarp of Copa Hill (referred to as Copper Hill in the mining literature) high above the River Ystwyth at 430m OD. It is the only mine working at Cwmystwyth for which there is evidence of prehistoric extraction. Beneath the opencast, the lode has been covered by extensive head (a soliflucted deposit consisting of angular rock debris in a silt-clay matrix) and its course exposed by eighteenth century hushing (Bick 1976). Here, the lode has been worked by a series of levels.

The ancient opencast measures approximately 45m in length, up to 17m wide and 5 or 6m in depth (Timberlake 1988c). Extensive tips from the working extend 85m downslope in three tongues and these have been variously estimated to contain 3500 and 4800 tonnes of spoil (Davies 1946; Timberlake 1991a). Hundreds of stone tools and fragments thereof are exposed on the surface of the tips where the turf has been denuded. A circular depression in the opencast marks the position of a run-in nineteenth century shaft to the Copper Level 27m below. Prehistoric tip material, including a stone hammer, has been found in the adit at this point (Timberlake 1988c) presumably derived from near surface collapse. A second opencast is located on a branch vein 150m downslope to the south. This is not thought to be of great antiquity as it is not associated with stone tool finds or evidence of fire-setting, and the side walls are not very weathered.

A number of shallow channel systems which feed into the opencast and skirt round its top have been interpreted as leats and peat sledging tracks. The lode below the tips has been extensively hushed, probably dating to the eighteenth century. Other features in the area also include a number of drystone walled platforms which may have served as foundations for peat drying stacks (Timberlake 1990a).

4.2.2 Geology and ore mineralogy

The country rock of the area is composed of a group of alternating beds of hard dark grits and shales know as the Cwmystwyth Formation of the Llandovery Series (Lower Silurian). These occupy a deep downfold on the axis of the Central Wales Syncline and form the highest of the mineralized beds in the central Wales mining district (Jones 1922, 6; Hughes 1959).

The Ordovician and Silurian rocks of the district are strongly deformed into NNE trending periclines with a wave-length of about 10km whose limbs contain minor folds with wave-lengths of around 1.5km (Cave & Hains 1986, 99, 105). These are faulted by large, steeply dipping, normal transverse faults which trend approximately ENE/WSW, often in sinuous and anastomosing courses (Cave & Hains 1986, 100, 105). In the east and north of the district they are complemented by minor strike faults (north/south trending). Although both sets of faults carry metalliferous sulfides, it is the ENE trending faults which are predominantly mineralized where they intersect anticlinal folds (Cave & Hains 1986, 130; Hughes 1959).

At Cwmystwyth, the lodes consist of ENE/WSW trending fissure veins (fig. 4.3). The two principal lodes, Comet and Kingside lodes, would appear to be subsidiary fissures within

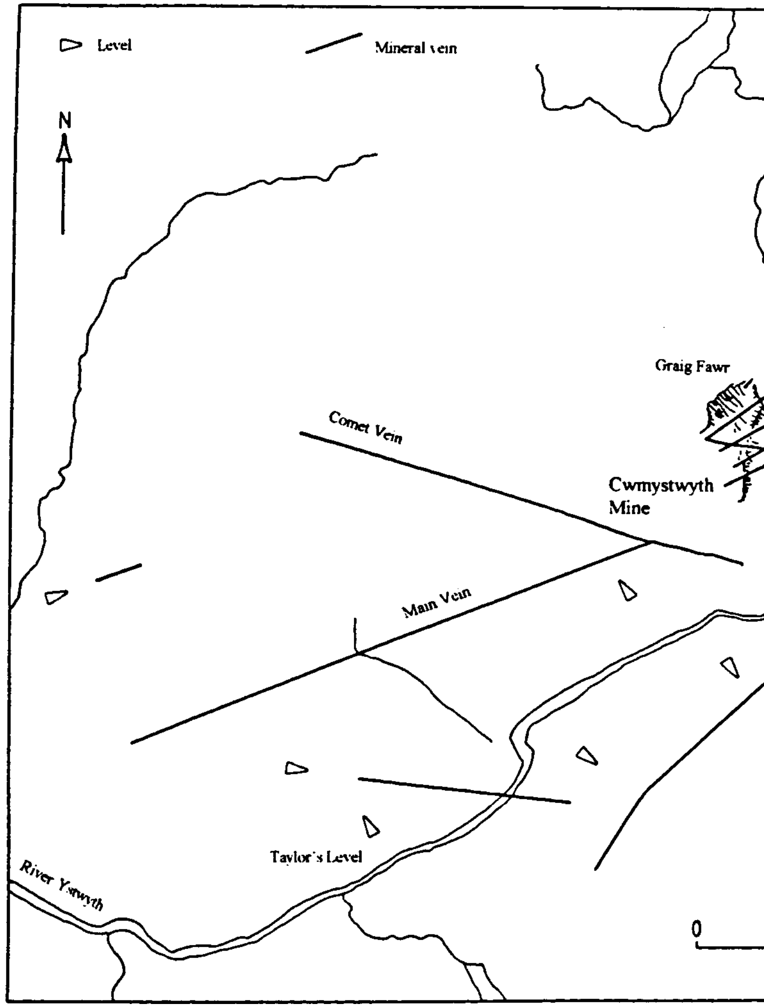
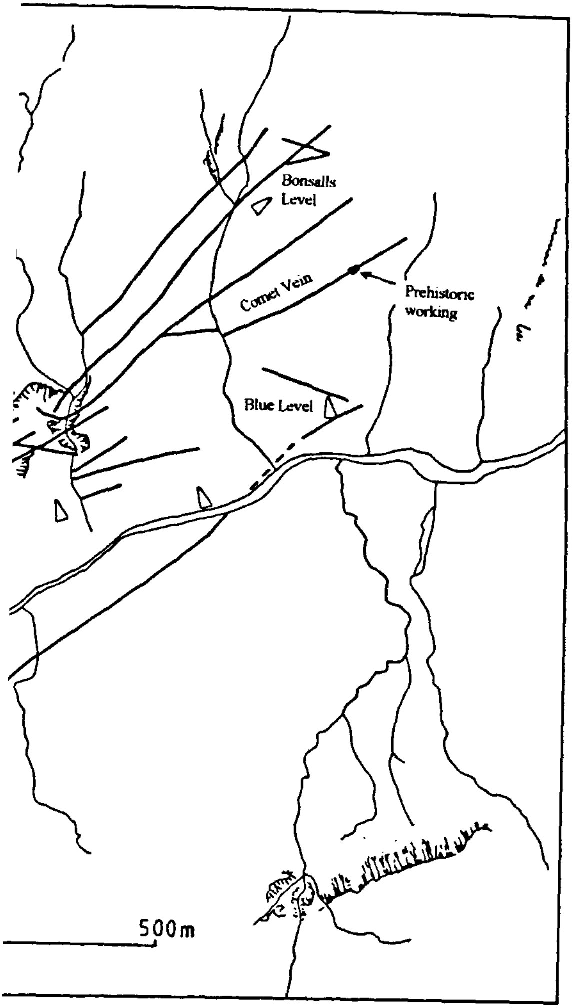


Figure 4.3 Map of the Cwmystwyth Mines (after Smyth 1848).



Bonsalls
Level
Comet Vein
Prehistoric
working
Blue Level
500m

a large fracture belt (Jones 1922, 30). They dip to the south and are cut off at depth by the Ystwyth Fault, dipping to the north, which is a major post-mineralization feature. The third main lode, Michell's Lode, is a comparatively short, mineralized, fault which dips to the north and downthrows both the Comet and Kingside lodes. The lodes are intersected to the west of the mine by the Ystwyth Fault which, after running parallel to the lodes, courses to the west along the north side of the Ystwyth valley two miles east of Pontrhydygroes (Jones 1922, 34), by which point the Comet Lode has become barren. The Fault has a displacement of two and a half kilometres and a downthrow to the north of about 1000m. The Logaulas Lode is thought to be the continuation of the Comet Lode on the south side of the Ystwyth Fault as it runs parallel to it three-quarters of a kilometre to the south. This lode was only productive at its west end (Jones 1922, 33).

In the west and central areas of the Cwmystwyth Mine the Kingside and Comet lodes run together. To the east of Graigfawr they diverge, the Kingside Lode to the north and the Comet Lode to the south, and then after about 1.2km they converge and reunite on the north side of the summit of Copa Hill (Jones 1922, 31). The large mass of rock sandwiched between the two lodes, known as a 'horse', is traversed on its western side by six or more richly mineralized strings. Although the lode belt can be traced north-east of Copa Hill for a further five kilometres, it is unproductive.

The Comet Lode is a very wide (3.6 to 12.2m) open lode with a clearly defined footwall which, due to its great proportions, proved to be the richest lode of the historic Mine (Hughes 1981b, 46). The Lode consists of breccia cemented by quartz, calcite and iron-rich dolomite (Jones 1922, 117). The main ore minerals are pyrite, galena and sphalerite, the latter two occurring in large continuous bodies. At Copa Hill, the lode contained a considerable amount of chalcopyrite in segregations, veinlets and quartz vugs (Timberlake 1988c). Small quantities of secondary copper ores, such as malachite, azurite, ~~limonite,~~

brochantite and posnjakite are present at surface and underground (Bevins 1994; Hughes 1981b, 48; Timberlake 1988c) and secondary lead and zinc minerals are also reported, i.e. cerussite, schulenbergite and smithsonite (Bevins 1994). Most oxidation zone minerals, however, would have been removed by glacial erosion. There is no zone of secondary enrichment. Native gold has also been reported. It has been suggested that in some instances chalcopyrite may have occurred more abundantly at surface than at depth (Smyth 1848).

4.2.3 Mining history

The history of the Cwmystwyth Mine has been described in detail by Hughes (1981b) and Lewis (1967). Although the first references to lead mining in the district date to the late thirteenth and early fourteenth century, the earliest record of mining at Cwmystwyth is not until about 1535 on the issue of a lease by the Abbey of Strata Florida (Hughes 1981b, 7). The early history of the mine is well documented as a result of legal disputes concerning the assignment of leases (an unsatisfactory position created by the dissolution of the monasteries and the creation of The Society of Mines Royal), illicit working and company fraud. The later history is similarly well recorded due to the survival of company records.

Most, if not all, early mining had been centred on Copa Hill. Leland's description of the Mine in the late 1530s confirms that considerable mining and smelting had already taken place (Smith 1906). The Mine would appear to have been worked fairly continuously throughout its history. The earliest mine working attributable to a specific mining venture is Herbert's Adit on the Kingside Lode dated to about 1670 (Hughes 1981b, 10). Historical workings identified for the Comet Lode on Copa Hill, are listed by Timberlake and Mighall (1992). The western section of the Mine was certainly being worked by the latter half of the seventeenth century (Hughes 1981b, 10). Mining operations declined considerably in the later years of the nineteenth century and the Mine eventually closed in 1921 (Bick 1976, 22).

For the years 1800 to 1939 it is estimated that 54,000 tons of lead ore were extracted and that total production may be in the order of 250,000 tons (Hughes 1981b, 49, 75). There are no output figures for copper as the mine had become exhausted of copper ore by the time that records were being kept, even prior to the introduction of the mineral statistics.

4.2.4 Archaeological background

The presence of stone hammers, associated with an old openwork at Copa Hill, was first reported by Smyth (1848). The site was first investigated by Davies in the 1930s, under the auspices of the British Association for the Advancement of Science (Davies 1946; Peake 1937). He noted that stone hammers were not to be found at any other mine workings in Cwmystwyth. Davies cut three sections through the tips, adjacent to the opencast, and recovered a small collection of stone tools. He also excavated a small test trench in the lower opencast, but found no evidence to suggest that this too was an ancient working.

In 1986 a similar small-scale excavation, together with a detailed survey of the area, was undertaken by Timberlake (fig. 4.4). Two sections were cut through the tips which were found to reach a depth of 2m. The tip contained appreciable quantities of charcoal and stone hammer fragments. Badly decayed fragments of red deer antler were also recovered (Timberlake 1987, 1988b; Timberlake & Switsur 1988). Three radiocarbon dates were obtained from charcoal contained within the tip to the Early to Late Bronze Age (table 2.1).

More extensive fieldwork was undertaken in 1989. This involved the investigation of the leat system and the infill of the opencast by excavation, a survey of the stone tools exposed in the surface of the tips, and a palynological study (Timberlake 1990a; 1990c; Mighall 1990; Timberlake & Mighall 1992). Excavations at the mouth of the opencast suggested that the infilled working had been used as a hushing reservoir. A trench, excavated to investigate the form of the opencast side wall and nature of the infill, was continued in

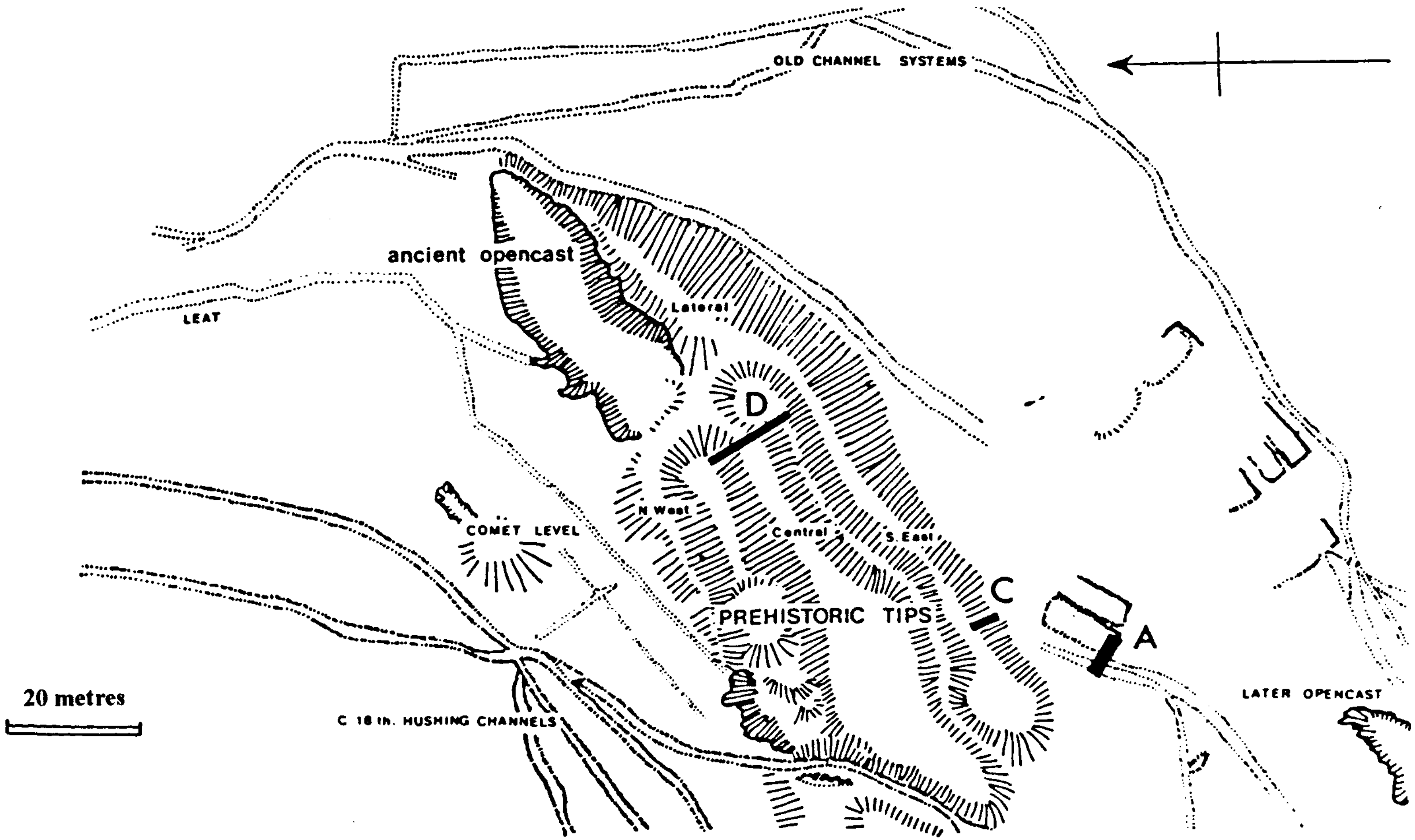


Figure 4.4 Plan of the prehistoric Opencast and mine tips at Copa Hill, Cwmystwyth (from Timberlake 1988b).

1990 and 1991. This exposed a small gallery-type working in the side wall and established that the main working continued to a depth of at least seven metres from the present infilled ground surface. This gives a total depth of working of approximately twelve metres. The working is infilled with shale scree and silt, interdispersed with peat horizons. Radiocarbon dates have been obtained for three of these layers and two for the floor of the working (table 2.1). These dates would appear to support the interpretation of a progressive infill of the opencast after abandonment in the Early Bronze Age and that the opencast is a largely intact Bronze Age feature (Timberlake 1990a; 1992). This interpretation has been confirmed by further excavations in 1993 which exposed a wooden launder on the side wall of the openwork which has been radiocarbon dated to the Early Bronze Age (Timberlake 1993; see table 2.1). There appears to have been some limited disturbance by an intrusive timber structure which has been radiocarbon dated as modern and medieval (Timberlake & Mighall 1992; Timberlake 1991b).

4.2.5 Stone tool collections

As a considerable number of stone tools and tool fragments are exposed on the tip surface today, these were sampled during a week of fieldwork in the summer of 1991. Specific scatters which could be pin-pointed on the 1989 tip survey plan (see Timberlake 1990c) were selected and all the pieces, from complete cobbles to spalls, were recorded. Material recorded in the field also included a collection of stone tools left on site from the 1989 fieldwork season.

Material recovered during the fieldwork of 1986 and 1989 is available for study at The National Museum of Wales and The British Museum. Specimens from later fieldwork were not available for study. Stone tools collected by Davies in 1937 are also held by The National Museum of Wales.

4.3 Parys Mountain

4.3.1 Site description

Parys Mountain, or 'Mynydd Parys', is a prominent hill in north-east Anglesey which rises to a height of 147m. Today the mine is dominated by two large opencasts on the Great Lode and a number of sets of precipitation tanks and feeder ponds. The northern slopes of the mountain are least disturbed by industrial activity and it is in this area that the remains of prehistoric tips survive. They are located on the north side of the summit windmill, on the northern edge of Oxen Quarry. They are distinguished from recent mine spoil by their very low relief and the fact that fragments of stone hammers are found at surface after heath fires. The extent of the tips has not yet been determined. Three further localities of stone hammer finds have also been made in the north-west area of the Mountain.

4.3.2. Geology and ore mineralogy

Parys Mountain is a relic hill (monadnock) which rises abruptly above the Menaian Platform. The polymetallic pyritic sulfide deposit is associated with a transgressive acid intrusion of the Upper Ordovician (fig. 4.5). These volcanics, the Parys Mountain Volcanics, were deformed into a synclinal structure during the Caledonian orogeny and they form the core of the mountain. Recent studies of the deposit (Pointon & Ixer 1980; Ixer & Pointon 1980) have been made possible by deep drilling for mining prospection purposes.

The volcanics unit, previously described as 'felsite' or 'felstone', is predominantly siliceous consisting of lavas (rhyolites and dacites), intrusive rhyolite and pyroclastics which grade laterally east into shallow water volcanic sediments (siliceous sinters, chert, shale and volcaniclastics). Three stratigraphic units have been identified which are underlain by Lower Ordovician shales (Parys Shales) and overlain by Silurian Shales (fig. 4.5).

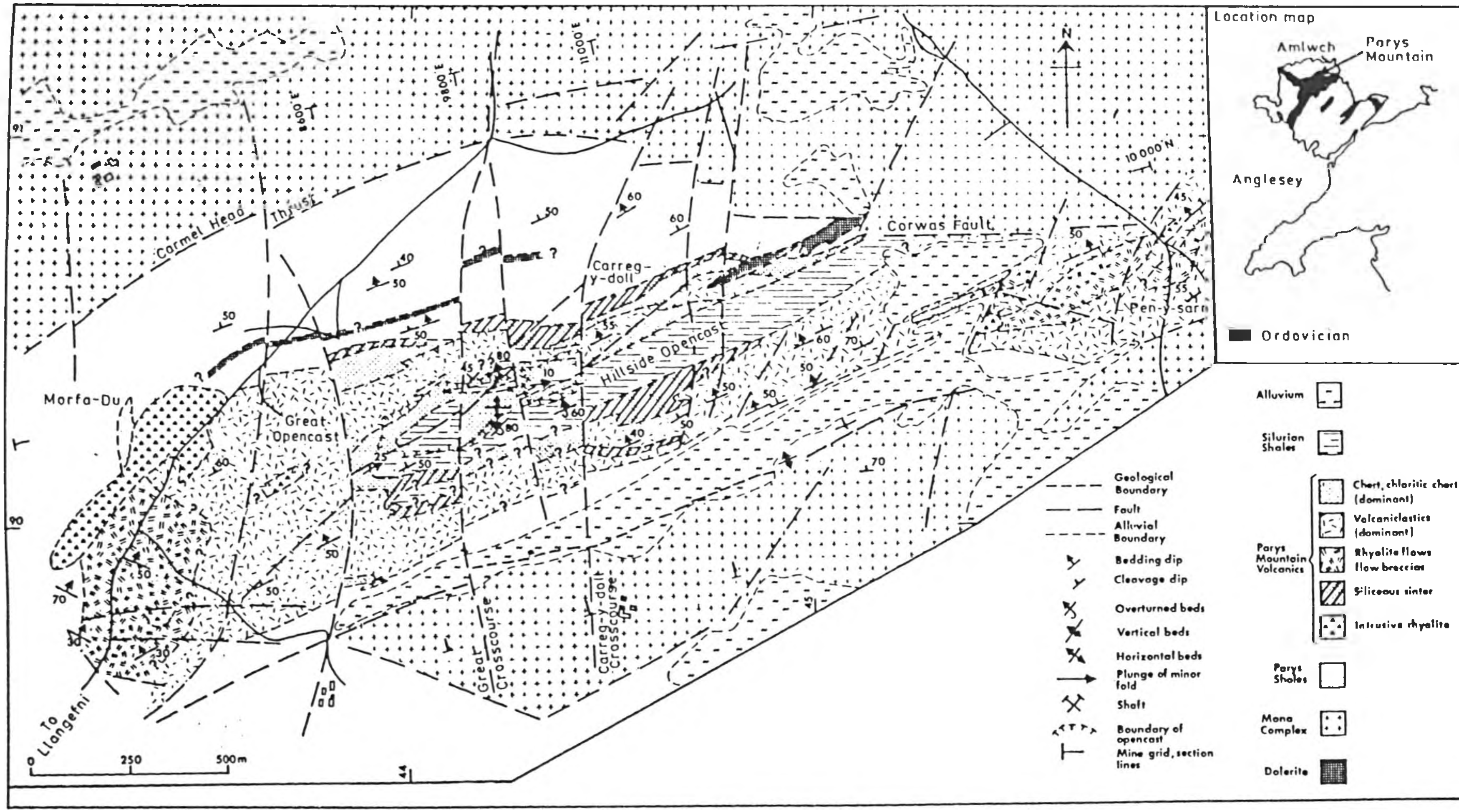


Figure 4.5 The geology of Parys Mountain (from Pointon & Ixer 1980).

The mineralized belt, striking north-east, extends to over 1500m in length and 350m in width (Manning 1959). The primary mineralization, which is believed to be contemporary with the Ordovician volcanic activity, occurred at both the base and at the top of the volcanics. (For a description of this process see Pearce 1993.) The ore deposit is comprised of pyrite and silica followed by a main phase of pyrite associated with later polymetallic mineralization of chalcopyrite, sphalerite and galena, and minor amounts of arsenopyrite, tetrahedrite group minerals and some rare bismuth sulphosalts and lead/copper antimony sulfides (Bevins 1994, 19). The ore has been described in the following terms: 1) pyrite-chalcopyrite ore contained in a fine quartz matrix, and 2) 'bluestone' ore consisting of a fine-grained, blue-grey rock containing an intimate mixture of sphalerite, pyrite, chalcopyrite, galena and chalcocite (Greenly 1919, 827).

The twelve main lodes (Greenly 1919, 829) can be grouped into three types (Pointon & Ixer 1980; Ixer & Pointon 1980):

1) Mineralization within the siliceous sinter and cherts. This occurs at the base of the Parys Mountain Volcanics and is represented by the Carreg-y-doll and Morfa-du lodes. Stratabound ore of both types are present. At the Carreg-y-doll Lode the chalcopyrite-pyrite ore is found in lenticular bands, of up to 0.5m in thickness and 2m in length, enclosed in a very hard fine-grained irregularly banded quartz rock (Pointon & Ixer 1980). These die out near to the surface, however, into a number of thin strings, and at surface only gossanous limonite is present.

2) Mineralization within cherts and shales. This type is found at the top of the volcanics and at the base of the Silurian Shales, known as the Great Lode. The mineralization occurs in bands and lenses within a fine-grained quartz and chlorite matrix. A rough zoning of ores has been recorded (Greenly 1919, 830) from pyrite to the north to chalcopyrite in the middle and then to bluestone to the south. Manning (1959) has suggested that some lenses must have

reached very considerable sizes: 55m in width and 210m in length. The Lode would appear to have been a pair of huge aggregates or bunches overlain by a zone of secondary enrichment. It is evident from old accounts that a considerable amount of gossan was present (Greenly 1919, 837).

3) Remobilized ore in fissure veins. The primary mineralization is cut by quartz-filled fissure veins which carry remobilized ore. These veins contain chalcopyrite and minor amounts of pyrite, galena and sphalerite. The most richly mineralized lode in the mountain, the North Discovery Lode, is of this type (Greenly 1919, 835). Later cross-faults contain only weak local mineralization.

Although considerable tracts of the north and west slopes of Parys Mountain are free of glacial drift, striae crossing close to the summit confirm that the hill was indeed submerged beneath ice during the last glaciation (Greenly 1919, 746). Further glacial features include miniature 'crag-and-tails' on the northern slopes (Greenly 1919, 699). Any surface oxidation of the northern lodes would have been removed by glacial erosion, whereas the southern lodes were sheltered. On the Great Lode twenty feet (6.1m) of boulder-clay has been recorded for the West Pit (Greenly 1919, 749).

4.3.3 Mining History

The first documented record of copper mining is for 1761 when Cartwright, mineral agent to the landowner Sir Bayly, reopened recently discovered old workings in the northern lodes (Harris 1964, 21). Two years later the mines were leased to Charles Roe of the Macclesfield Copper Company whose efforts floundered until a great mass of low grade ore was discovered in 1768. Most writers attribute this to the Great Lode (Greenly 1919, 825). This marked the start of major production which lasted up until 1883 when underground work was suspended. As the mountain was divided between two estates, the Great Lode was mined by separate operations until the formation of the Parys Mountain Company in 1778. Under the management of Thomas Williams, the mine dominated the world copper market in the late eighteenth century producing some 5000 tons of copper annually for the first twenty years (Manning 1959). Copper was also extracted from groundwater by precipitation in tanks containing scrap iron from an early date (Briggs 1992). 'Cement' copper, as it was known, was recovered in this way until the 1950s. In total, it is estimated that some 130,000 tons of copper metal have been extracted from between 2.6 and 3.7 million tons of ore (Manning 1959).

4.3.4 Archaeological background

Finds of at least three bun-ingots or 'copper cakes' in 1871 at Bryndu to the north-west of Parys Mountain (Stanley 1873; Evans 1873), led many earlier writers to speculate that the Romans had mined there. Two of them had been stamped with a circular die bearing the Latin letters 'IVLS'. No further finds have been made.

Eighteenth and nineteenth century descriptions of 'old man' workings are given in section 2.7.2. In addition, Evans (1873) notes that ancient workings were located close to the road leading from Pengarnedd to Gareglefn. Other discoveries include that of an ancient smelting hearth of stone and small pieces of smelted lead (Pennant 1778, vol. 3, 58).

The ancient tips were first sectioned by Davies in the late 1930s. These contained charcoal, vein material and numerous stone hammers and fragments thereof (Davies 1939; Peake 1937). A small stone disc was also found. The site was re-investigated by the Early Mines Research Group in 1988. This involved the limited mechanical excavation of three trenches in the north-east sector of the same tip feature (Timberlake 1988d; 1990d) which was interpreted as an '*in situ*' prehistoric tip (fig. 4.6). Three radiocarbon dates to the Early Bronze Age were obtained from charcoal within the tip (Ambers 1990; Timberlake 1989; see

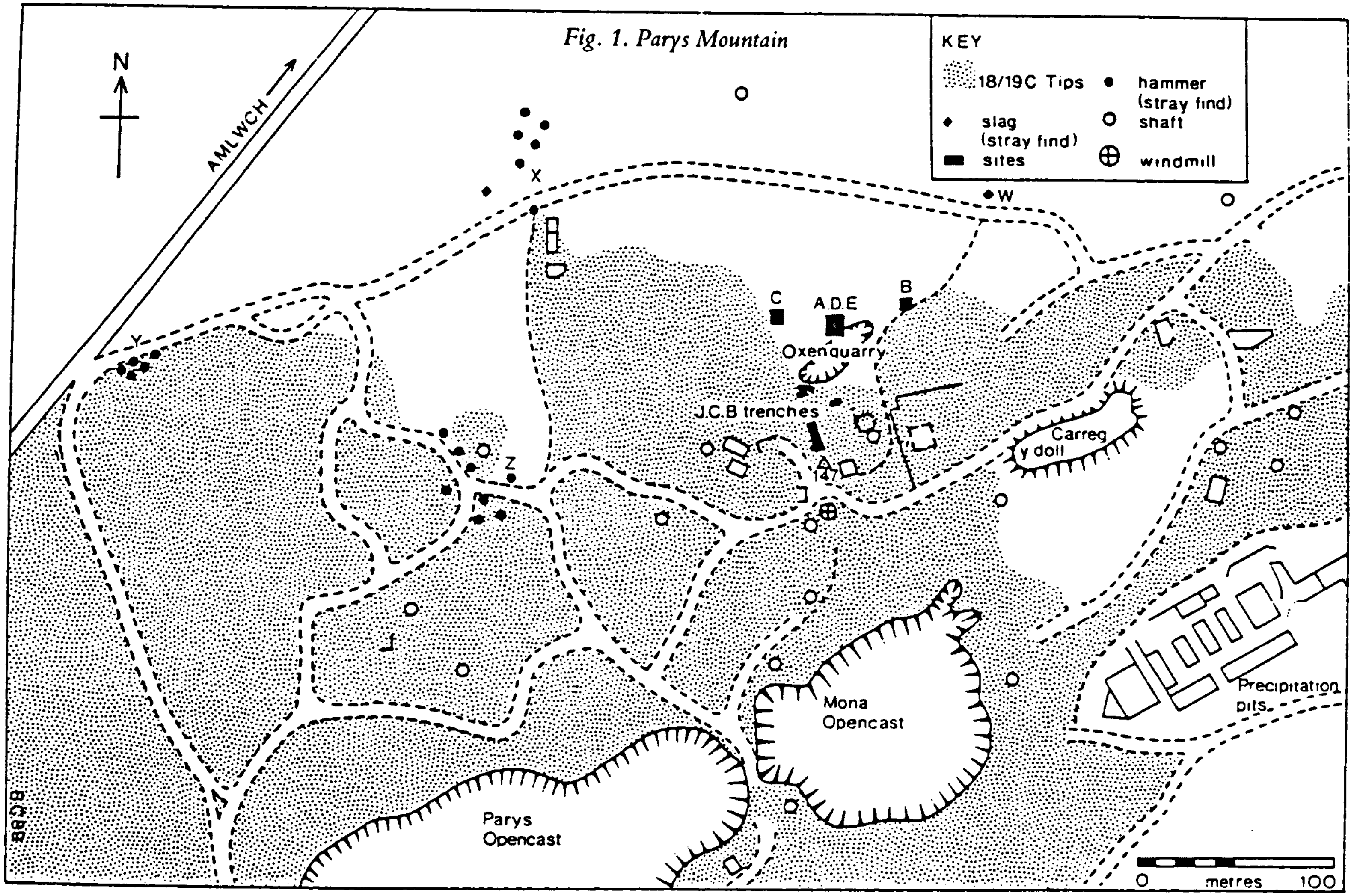


Figure 4.6 Location plan of fieldwork investigations carried out on Parys Mountain in 1988 (from Timberlake 1990d).

table 2.1). In addition, fieldwalking on the north-west slopes of the Mountain identified three further sites of prehistoric mining activity.

This fieldwork corroborates earlier documentary reports that prehistoric workings were located in fissure veins in the northern lodes. These would have been the only lodes accessible to the prehistoric miner as the northern slopes are free from glacial drift.

4.3.5 Stone tool collections

A small number of stone mauls were recovered, evidently from old workings, at Parys Mountain during the nineteenth century (Stanley 1850). A small collection of stone tool fragments, collected from Davies's excavation, were deposited with the Museum of Welsh Antiquities at Bangor (Peake 1937). The largest body of material was recovered by the Early Mines Research Group and this is divided between The National Museum of Wales and The British Museum.

4.4 Nantyreira

4.4.1 Site description

The mine of Nantyreira, also known as 'Snowbrook', is situated on the eastern slopes of Plynlimon. The course of the lode is followed by the Afon Hore which now flows through the openwork. The mine working consists of an open trench 95m long, 6m wide and up to 7m deep (Timberlake 1988d; 1990d). The base of the trench has been worked by a nineteenth century level from which a tramway issues south to dressing floors (fig. 4.7). The top margins of the openwork appear to have been worked by fire-setting. The eastern edge of the mine is flanked by a ridge of prehistoric spoil some 50m in length. Disturbed ground some 400m to the south may suggest the shallow working of a subsidiary lode (Bick 1983, 30).

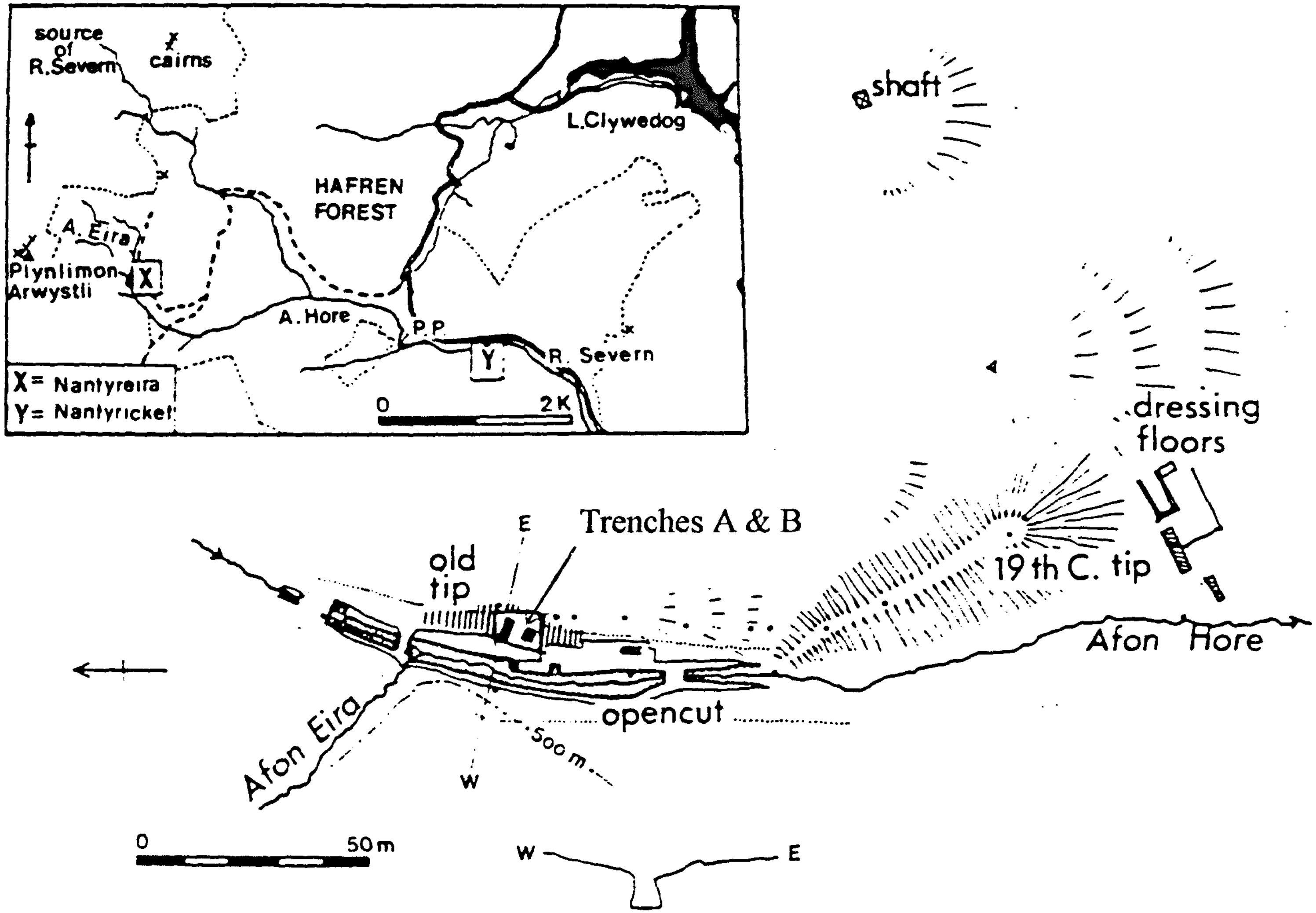


Figure 4.7 Location map and plan of mine workings at Nantyreira (from Timberlake 1990d).

4.4.2 Geology and ore mineralogy

The structure of the central Wales mining field is introduced in section 4.3.2. The lode is formed by an almost vertical fissure or normal fault, trending north/south along the crest of a sharp anticline (Jones 1922, 9 & 176). The lode traverses the upper grit beds of the Lower Van formation which belong to the Ordovician. Jones (1922, 176) noted that, within the working, narrow strings of galena can be seen in the joints contained in the grit beds. These are known as 'flats' and they only occur in this formation (Hughes 1959). For more specific details concerning the nature of the mineralization at Nantyreira it is necessary to examine the literature on Nantiago, which is situated on the same lode three-quarters of a mile to the south. Here, the one to two metre wide fault breccia is cemented not by quartz, which is the norm, but by calcite (Jones 1922, 163; Bevins 1994, 51). This contains strings and spots of sphalerite and galena. The lode was mined for lead and silver. Although there is no mention of copper ore at either Nantyreira or Nantiago in the mining literature, Timberlake (1988d, 1990d) reports that there is a significant presence of chalcopyrite. This is unusual since lodes contained within the Van Formation are generally lacking in copper ores (Jones 1922, 181; Hughes 1959, table 1).

4.4.3 Mining history

In 1858, the first reference to mining at Nantyreira describes when Captain Reynolds of Llanidloes rediscovered the openwork which he then started to rework in the following year (Bick 1983, 28). The mine was worked intermittently by various parties until 1883. The mine was small; the recorded returns for a total of six years between 1859 and 1883 only amounted to 161 tons of lead ore (Jones 1922, 177).

4.4.4 Archaeological Background

When the old workings were cleared out in 1859 a number of artefacts were recovered from the bottom of the working at a depth of 50 to 60 feet. These consisted of an iron pick with a wooden handle, 'a ponderous ball of stone' 3½ inches in diameter, which was thought to have been used for ore-dressing, and 'a portion of a stag's horn fashioned so as to be suited for the handle of a stone implement' (Anon 1860; Jones 1922, 176). The stone was also described as a 'buckering stone' (Barnwell 1870). They were given to Sir Hugh Bodelwyddan who then presented them to the Duke of Northumberland whose collection of antiquities formed the museum housed in the Postern Tower of Alnwick Castle. Unfortunately, these finds are now thought to be lost (Timberlake 1988d).

In the 1930s Davies excavated two small sections in the tip lining the east side of the opencast (Davies 1938). The Early Mines Research Group excavated two further sections in the same tip in 1988 (Timberlake 1988d; 1990d; see fig. 4.7). Two phases of mine tipping were identified, the earliest of which yielded charcoal and stone hammers. Two C14 dates to the Bronze Age were obtained from charcoal samples (Ambers 1990; Timberlake 1989; see table 2.1). Surface finds of stone hammers were also made at the site of the nineteenth century tramway and this was interpreted as material cleared out of the 'old-man's work' when the mine was reopened in 1859.

4.4.5 Stone tool collections

The finds from Davies's excavation which were sent to the Powysland Museum at Welshpool (Peake 1937) have not been located (Bredsdorff pers. comm.). The only material available for study is from the 1988 excavations and this is held at The National Museum of Wales and The British Museum.

4.5 Alderley Edge

4.5.1 Site description

Alderley Edge is a prominent northward-facing scarp which rises 100m above the Cheshire Plain, some twenty kilometres south of Manchester. The mining district includes Mottram St. Andrew which is one mile to the north-east of the Edge. The remains of limited prehistoric mining pits are still visible at surface at Engine Vein Mine and Pillar Mine. In these areas finds of stone hammers, usually finely grooved, are not uncommon amongst eroding mine spoil (fig. 4.11). Prehistoric workings were first discovered in the area of Brynlow, but these have long since been filled in. Other finds were made at the mine of Mottram St. Andrew. Today, there is little surface evidence of the mine surviving except for the remains of a quarry, landscaped and incorporated into the garden of a private house.

4.5.2 Geology and ore mineralogy

Alderley Edge consists of a three kilometre wide horst of lower Triassic rocks bounded by major north/south trending faults known as the Kirkley Ditch and Alderley faults (fig. 4.8). The scarp is formed by repeated normal faulting (fig. 4.9), which trend, approximately, west-north-west/east-south-east (WNW/ESE). This exposes rocks of the Helsby Sandstone Formation (formerly called the Lower Keuper Sandstone) which is relatively hard compared to the underlying beds of Wilmslow Sandstone Formation (formerly called the Bunter Upper Mottled Sandstone). To the south these are overlaid by younger units of the Helsby Sandstone formation. All of these beds dip between 10 and 14 degrees to the south-west.

Mineralization in the Cheshire-Shropshire Basin is related to faults bounding its margins. In general terms, the mineralization type is hydrothermal, but the exact form of genesis is not agreed (see Thompson 1991 for details). The Alderley Edge ore deposit is strataform and non-ferrous, a type which has been described as a 'red-bed' formation (Holmes

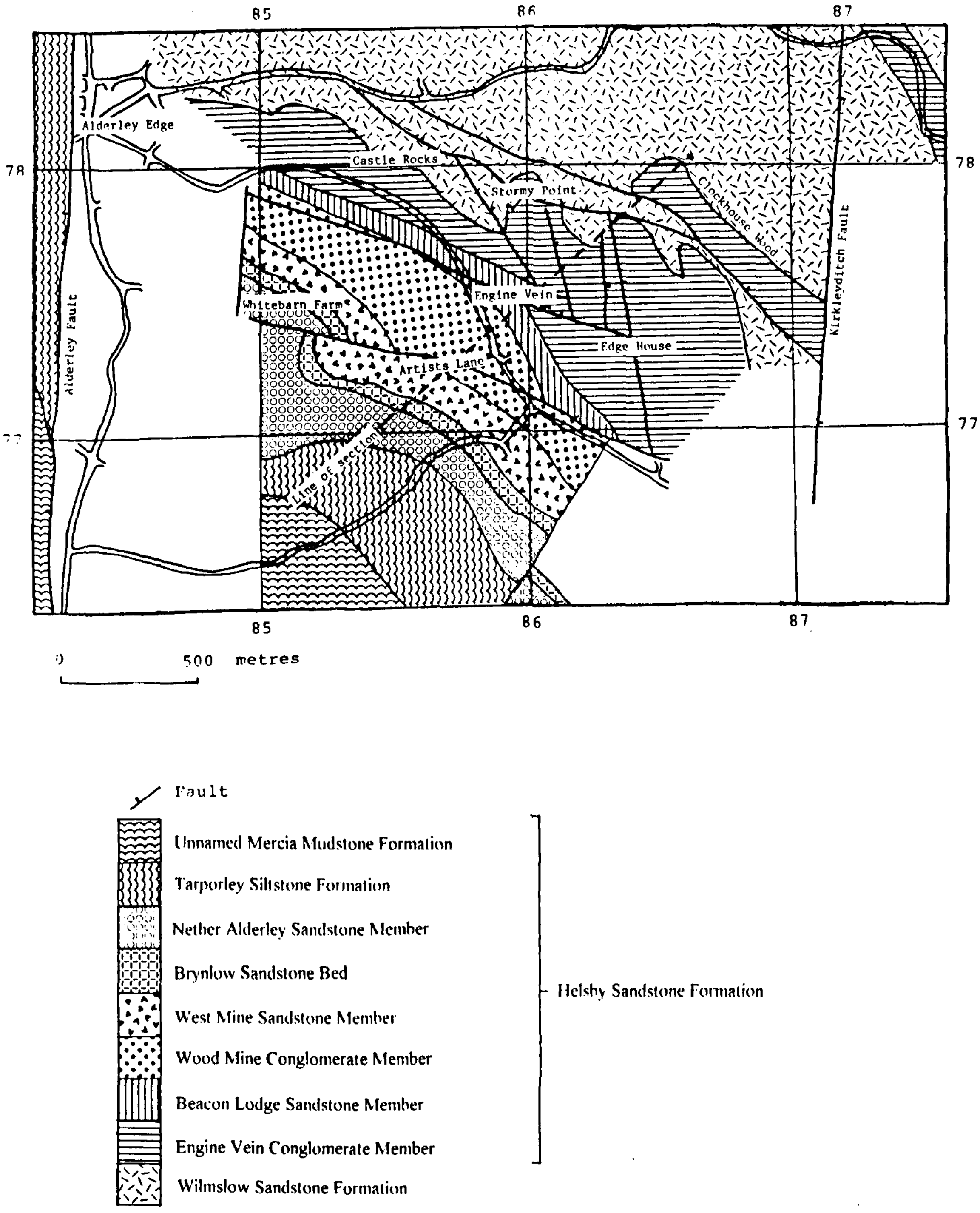


Figure 4.8 The geology (solid) of Alderley Edge (after Thompson 1970, 1991 - areas where the geology is not well known are left blank).

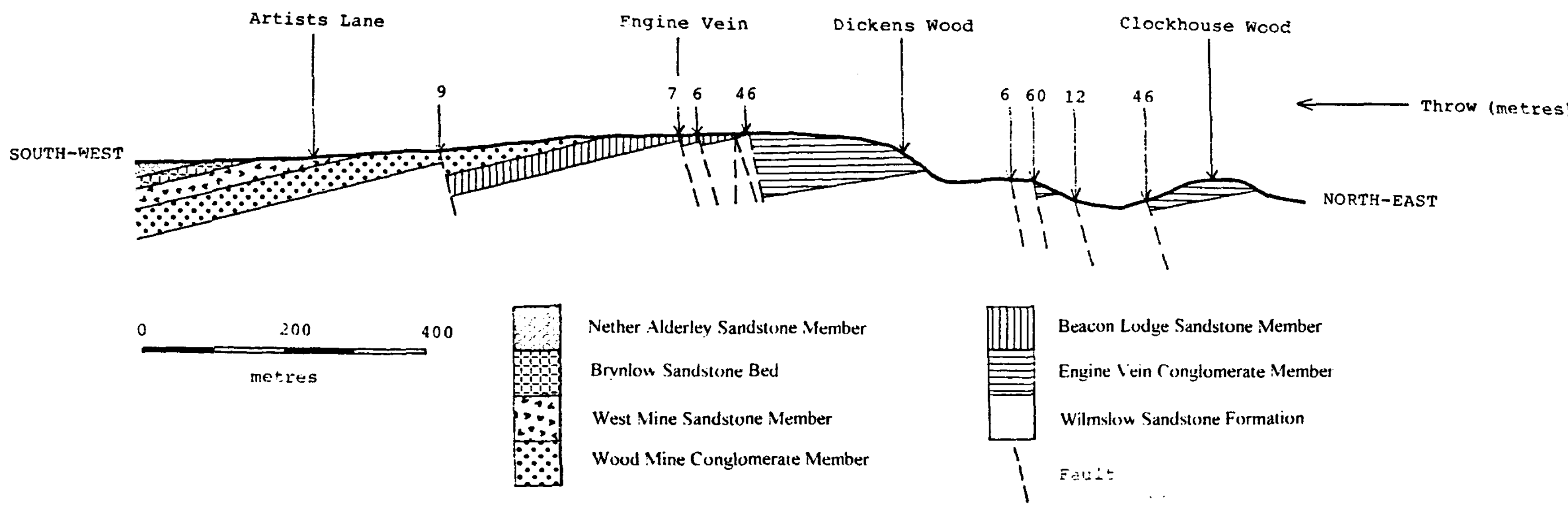


Figure 4.9 Geological section across Alderley Edge (see fig.4.8). (After Thompson 1970, 1991.)

et al. 1983; Warrington 1980). The ore consists chiefly of carbonates and, more rarely, sulfides and oxides, of copper, lead and zinc (copper being the principal ore). Minor amounts of silver, cobalt, arsenic, nickel, manganese, antimony and gold have also been recorded (Warrington 1965). The ore is found chiefly within three conglomerate and sandstone units in the Helsby Sandstone Formation (the Engine Vein Conglomerate, Wood Mine Conglomerate and West Mine Sandstone Members), and in insignificant amounts within the top six metres of the Wilmslow Sandstone Formation (Ixer & Vaughan 1982). The ores occurred in massive form in the fault breccias and as disseminations within the sandstone infilling pore-spaces and as a cement between sand grains (Ixer & Vaughan 1982). The gangue mineral is barytes which is widely disseminated throughout the rock, extending locally beyond the metalliferous impregnations, as well as occurring in massive form in faults to produce vein-like deposits (Taylor *et al.* 1963). The mineralization is closely associated with the fault system. While lead and zinc minerals are restricted to the faults, copper mineralization has a much greater dispersion migrating down-dip from mineralized faults (Warrington 1965). Similarly, the distribution of remnant primary sulfide minerals, which occur only in small amounts, are restricted to faults whilst secondary minerals are much more widespread. Several of the WNW/ESE trending faults are richly mineralized (e.g. the Engine Vein Fault) whereas minor north/south trending faults are unmineralized except for barytes. In conclusion, it would appear that the primary mineralization was associated with the fault system and that this has been significantly altered and redistributed by groundwater in an oxidizing environment.

The principal and, indeed, most widespread copper ore is malachite. It is concentrated along certain fault lines, from which nodular forms have been recorded (Green pers. comm.). The richest disseminations occur both immediately above clay bands and between clay flakes within mud-cracked clay bands. Azurite and chrysocolla are not as common and these are usually found near faults (Warrington 1965). Other minor copper mineral species that have been recorded include silicates, arsenates, sulfates, oxides and native metal. Sulfide minerals, associated with lead ores, are scarce. For lists of reported mineral species see Warrington (1965), Carlon (1979) and Thompson (1991).

Lead ores consist predominantly of cerussite and galena and these occur in massive form in fault breccia. They are always found in association with barytes gangue and rarely occur in the Wilmslow Sandstone Formation. Galena exists sporadically and with wide intervals between occurrences (Taylor *et al.* 1963). Hull (1864) reported that disseminated galena formed up to 30 to 40 percent of the rock by volume.

The mine workings cover an area of about 1.5 square kilometres (Warrington 1980) and they are described by Dewey and Eastwood (1925) and Carlon (1979; 1981).

4.5.3 Description of the areas associated with prehistoric mining

The escarpment and the area extending south towards the south side of Macclesfield Road is drift free (fig. 4.10). This area encompasses all the sites exploited in prehistory with the exception of Brynlow Levels which is covered by a thin deposit of boulder clay. Mineralized faults in the region of Stormy Point would have been outcropping and the Engine Vein Fault most likely outcropped at its east end by the lane to Edge House. The line of the fault was probably visible at surface as a shallow trough and, therefore, easily located without prospection. It would appear that the lodes at Mottram St. Andrew may have outcropped at surface in a small drift free island.

The Stormy Point area consists of a mineralized WNW/ESE trending fault, the Stormy Point Fault, complicated by a series of minor north/south trending faults. These faults mostly contain lead ore and barytes, although specimens of azurite and nodular malachite have been recovered from the area (Green pers. comm.). The Engine Vein Mine shows the

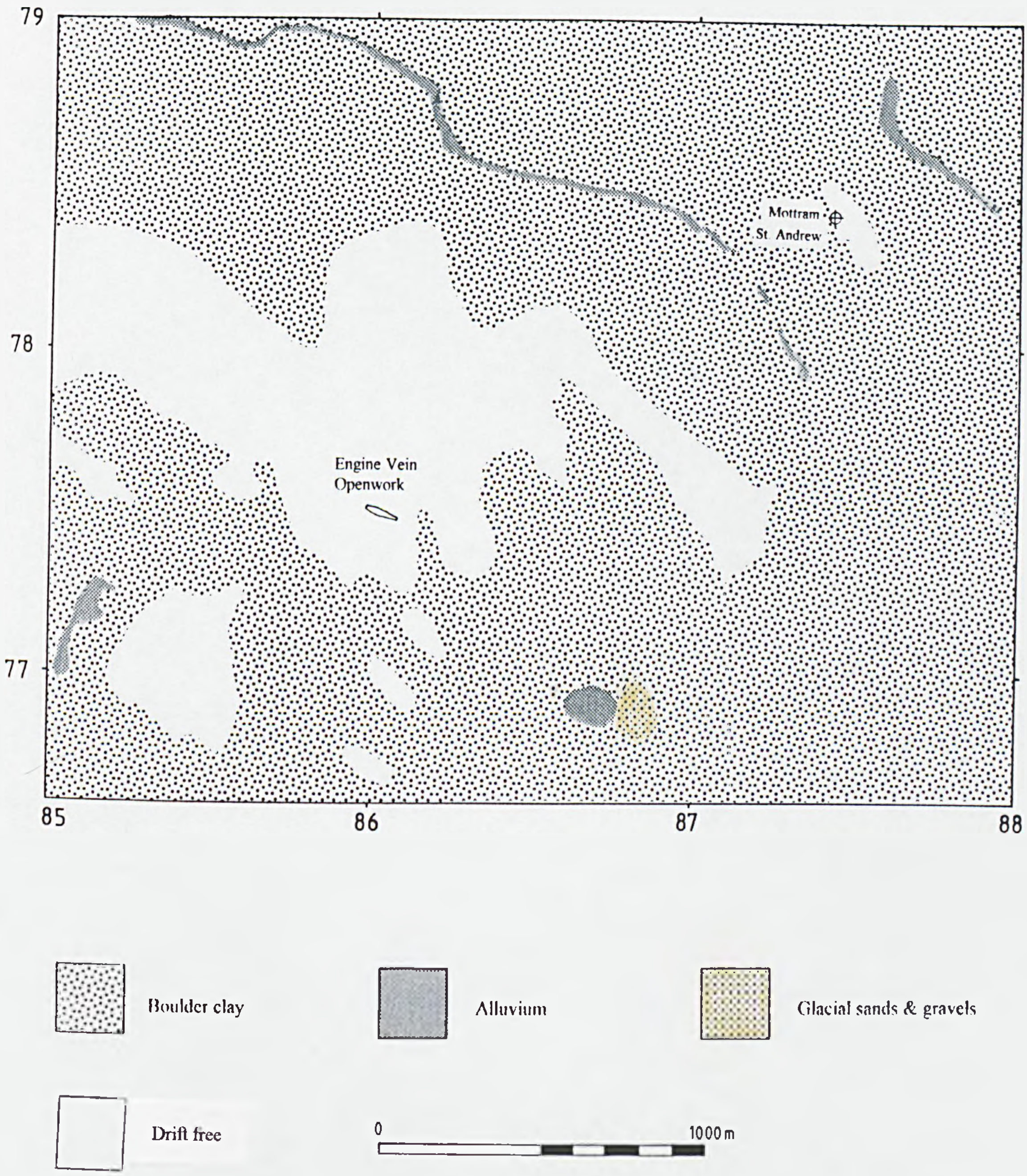


Figure 4.10 The geology (drift) of Alderley Edge (transcription of the BGS 1:10, 560 geology map, provisional edition 1961, sheet SJ 87 NE).

greatest degree and variety of mineralization. This is associated with a double WNW/ESE trending fault line, the main fault being known as the Engine Vein Fault which hades 60 degrees to the north (Warrington 1965). It was richly mineralized with lead ore which had formed a vein-like deposit. Copper mineralization was localized and it was the only lode where azurite was moderately abundant (Warrington 1965).

There are few details concerning the structure and form of the mineralization at the Brynlow Levels and Windmill Wood sites. Both sites are located on faults which are locally mineralized (Warrington 1965) but they are not known to be particularly rich at surface. It is probable that the Mottram St. Andrew find is also associated with a vein-like body known as the North Lode. This is described in some detail by Greenwell (1866). This was particularly rich in copper ore, containing up to 25 percent copper, although it quickly became unproductive with depth.

4.5.4 Mining history

The history of the mines has been described in detail by Carlon (1979) and Warrington (1981). The first historical record to mining on the Edge dates to 1693 concerns a dispute between mining parties. No details of the location of the workings are given, but it would appear that only a small workforce was employed. Although a number of parties worked the mines during the eighteenth and early nineteenth century, very few workings can be specifically attributed to any of these operations. This includes the Macclesfield Copper Company (1758-68) who mined the Edge extensively before making their discovery at Parys Mountain. No output figures exist prior to the first publication of the Mineral Statistics in 1845. These early mining operations would have been located in the eastern-half of the mine, at places such as Engine Vein and Dicken's Wood, concentrating on mineralized faults and associated areas. It is unlikely that mining on any significant scale had taken place in the area west of Wood Mine before the mid-nineteenth century. Both copper and lead ores were extracted. Cobalt ore was recognized in 1806, probably at Mottram St. Andrew, and soon mined by the Alderley Mine Company (1804-1810) close to Church Quarry (Thompson 1991).

The period of the Alderley Edge Mining Company (1857-78) marked a new era in the scale of mining operations with the introduction of a new acid treatment for the ore. This meant that the low grade copper ore disseminated in the sandstone beds, containing an average of around 2½ percent copper (Hull 1864; Higgs 1858), could be profitably extracted. Although mining was carried out in several parts of the Edge, including Wood Mine and Stormy Point, the principal works were located to the west of Wood Mine at West Mine. As well as extracting copper and lead, concentrates of cobalt, nickel and silver, subject to market fluctuations, were produced. The total output for this period amounted to 168,269 tons of copper ore (3,486 tons metal) and 274 tons of lead ore (Burt *et al.* 1990, 98). In the early part of the twentieth century there were two further ventures both of which were small scale and mining operations ceased in 1919.

The first records of mining activity at Mottram St. Andrew date to the early nineteenth century when, apparently, lead ore was extracted. In 1860 mining recommenced, but operations were relatively short-lived, being suspended in 1865. The only output figures available are for 1864 during which 14 tons of copper metal were extracted from 1000 tons of copper ore (Burt *et al.* 1990, 99). Cobalt was also extracted.

4.5.5 Archaeological background

Discoveries in the late nineteenth and early twentieth century of ancient mine workings and spoil associated with stone hammers came about due to the new mining strategies adopted as a result of the acid treatment process. Rather than reworking the old mines located on mineralized faults, they extracted sandstone beds containing low grade ore. It was whilst following such a mineralized bed to surface at Brynlow in 1874 that Dawkins made the first discovery of old pit workings containing stone hammers. A brief account of this was published in 1875 (Dawkins 1875) and reprinted in the following year. The only surviving field notes consist of Dawkins' year notebook in which he recorded the dimensions of seven pits (see section 2.7.2). He managed to secure thirty-five stone mauls for the museum at Owens College (which was later to become Manchester Museum) as well as donating small collections to a number of friends and colleagues. An oaken spade, illustrated by Sainter (1878, 64), was also recovered from these workings. This has recently been donated to The Manchester Museum and has been radiocarbon dated to the Middle Bronze Age (Garner *et al.* 1994; see table 2.1). By the time Roeder and Graves made similar discoveries at the turn of the century at other sites on the Edge, the Brynlow workings had been infilled. Recent surface finds suggest that the original site was located close to the shaft marking the junction between the Hough Level and a level connecting Wood Mine and Bynlow Levels at SJ 854 774 (Garner pers. comm.).

Around the turn of the century Roeder and Graves recovered numerous complete and broken stone mauls from recent mine tips at a number of other mine sites on the Edge, namely Windmill Wood, Engine Vein and Dickens Wood (fig. 4.11), as well as the neighbouring copper mine at Mottram St. Andrew (Roeder 1901; Roeder & Graves 1905; manuscript notes held by Manchester Central Reference Library, M277/3/2/1-15). These discoveries were made in modern spoil resulting from mining ventures carried out by the same company which uncovered the ancient mine workings at Brynlow. At Engine Vein, Roeder and Graves recorded the existence of five superficial pits which survived in section in the north mine face of the openwork (fig.4.12). They were able to excavate the middle pit as it was the only one with a rock floor separating it from the open stope below. They

Figure 4.11 Areas of stone hammer finds on Alderley Edge.

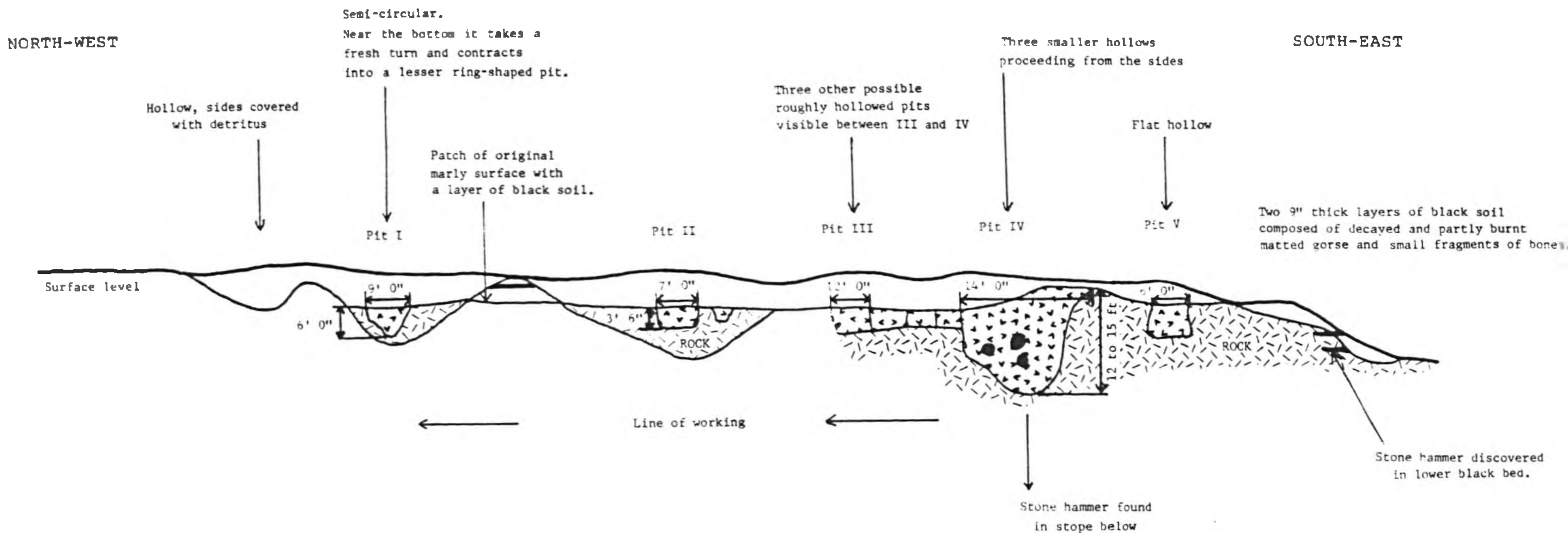


Figure 4.12 Sketch section of the superficial mining pits at Engine Vein Openwork, Alderley Edge (after Roeder & Graves 1905).

recovered charcoal, gorse, small bone fragments and a stone hammer. A metal object was also found which was thought to be the remains of a Roman iron pick, but a later worker considered it more likely to be a boring rod used in the nineteenth century to drill shot holes for blasting (Warrington 1981). Examination of the mining face (Gale 1986; 1989) suggested that the form of the pit workings is so well preserved because the pits remained filled with mine debris until the later half of nineteenth century when stopes had been cleared of their deads and timber. This formed a deep open trench working which was for safety reasons capped by a concrete ceiling in the late 1970s, unfortunately damaging some of the pit workings. The remains of a similar pit was excavated by Roeder and Graves on the north side of Pillar Mine entrance (SJ 861 778). The mine spoil in this area has been disturbed by mechanical landscaping in the 1950s (Pickin pers. comm.).

A number of fieldwork projects have been carried out more recently. In the late 1970s Manchester Museum undertook an earthwork survey to the west of Engine Vein Mine. In 1986, the author recorded in detail part of the pit workings in the mine face at Engine Vein Mine (Gale 1986; 1989). Limited excavation of surface workings were undertaken in 1991 at Brynlow, Wood Mine and a number of locations along the Engine Vein Fault, including the west end of the Engine Vein Openwork (Gale 1993). No further evidence of prehistoric mining activity was discovered.

The evidence to date suggests that although Bronze Age mine working was widespread, having being identified at five separate locations, it was very limited in extent. The mining was confined to richly mineralized sections or pockets along fault lines close to where they outcropped.

4.5.6 Stone tool collections

Stone hammers recovered by Dawkins and Roeder and Graves are held by Manchester

Museum. Unfortunately, the remainder of Graves's collection would appear to be lost (Crossley pers. comm.). Further material was traced through the county SMR, personal contacts and a letter survey of museums. A small collection of implements recovered during recent fieldwork by the author were available, as well as a number of specimens in the possession of the Derbyshire Caving Club and private individuals.

Notes

1 A term used to describe the angle of inclination from the vertical of a structural surface or a mine working.

CHAPTER FIVE

The Descriptive System for the Analysis of Cobblestone Tools

5.1 General considerations

The descriptive system has been devised to satisfy the following objectives: 1) to classify the material into functional types, 2) to characterize the physical properties of the material in order to examine the strategy and degree of control in the selection of suitable raw material in the types identified, 3) to identify sediment types or sources from which cobbles are derived, 4) to examine the possibility of functional specialization within tool classes on the basis of cobble size and morphology, and 5) to measure the consumption of tools. Consideration of these areas will then lead to the construction of higher-level theories concerning prehistoric mining strategies.

The description of the stone tools divides into three areas; 1) natural form, 2) use-wear, and 3) hafting or handgripping modification. The first part involves the recording of physical properties relating to the functional performance of the cobblestone tool, such as shape, hardness and the degree of surface smoothness. This includes the detailed examination of surface marks as these may be used to identify cobbles derived from, for example, glacial/periglacial deposits. The identification of other natural surface marks and textures is also important so that these can be distinguished from anthropogenic use and modification. It is also borne in mind that certain natural features may have been intentionally selected, for instance natural fracture surfaces would have been more suited to ore-dressing than abraded ones. The second part, the recording of use-wear, is undertaken at a macroscopic level in order to identify ore extraction and dressing processes, and to study tool consumption, i.e. the degree to which tools are used-up and broken. Microscopic examination is thought to be inappropriate in this case for reasons discussed below. Use-wear marks and forms are recorded in detail in order to examine evidence for specialization within tool classes. For the final part, the form of modification, presumably for hafting, although handgripping cannot be ruled out, is recorded. The recording is arranged for practical convenience; those for modification being left to last because the majority of pieces, for all but the Alderley Edge assemblage, do not show such evidence.

The classification of unshaped stone tools is traditionally based solely on the form of use because of the absence of other distinguishing characteristics. For this study a more detailed and explicit description of use-wear is necessary because some of the material shows multiple use which is, more often than not, associated with a change in form of the original stone piece through damage or breakage. This means that several ordered levels of recording are required so that the use-wear is placed in the context of other usages. The actual quantification of use-wear is limited because of the natural intractability of stone, more especially for the rock types represented in these assemblages. As previous studies have noted, the distinction between modification and use-wear marks may be difficult to make. This descriptive system has, therefore, been designed so that all marks, regardless of interpretation, are recorded in the same manner. This introduces some objectivity into the distinction between the two forms as well as allowing for possible reassessments or further comparisons at a later date.

As these stone tools are, almost exclusively, used for rock breaking and crushing, they can exhibit a high degree of damage and breakage which is a particularly restrictive factor in subsequent data analysis. Although it would be tempting to record only relatively complete tools in order to save time and secure a more complete data set for statistical analysis, there is the danger that this may not be representative of the tool population as a whole. For example, if tool fragments and spalls were excluded, properties that may have been preferentially selected in the heavier duty tools would be overlooked. Moreover, unsuitable qualities would be preferentially recorded for relatively complete tools which may have been found to be unsatisfactory and discarded at an early stage. It is clear that in order to avoid potential recording biases, all material must be recorded even though the amount of information extracted in some cases will be very limited. The inclusion of all pieces, to a practical limit, is also necessary in order to quantify and characterize reuse and recycling of tool fragments and spalls. A number of physical properties can still be recorded no matter how small the unutilized fragment, i.e. rock type, hardness, and, in most cases the surface texture and smoothness of the natural stone. In many cases, part of the area of working survives and the function of the original tool can be surmised. All unused cobblestones of rock types whose presence could not have been accounted for by natural agencies were also included in the study.

Due to the high degree of breakage exhibited by this material close attention needs to be paid to the recording methods in order to maximize the amount of information that can be obtained. In some cases, for example, the type or degree of damage to a measured property may be of interest in itself. In this instance, the size dimensions of a damaged stone maul records its discarded size which can then be related to the lower size limits of serviceability for that tool class. In order to use this type of information 'damaged' and 'broken' classes have been introduced to classify axial dimensions.

When dealing with assemblages where artefacts are commonly damaged, the quantification of tool types or certain features is made difficult because their survival or identification may be influenced by damage and because fragments represent an unknown number of artefacts. For example, modified hammers will tend to be under represented as the identification of haft modification for fragmentary pieces is made difficult by its irregularity in form and position. It is also possible that certain tool types may be under represented because they have undergone more damage due to the way in which they have been used. An assessment of the degree of use and damage is, therefore, incorporated into the recording system.

Where material is fragmentary a scoring system can be used to account for attributes which are unscoreable or absent as a result of damage or fragmentariness. It has not been practical to record haft modification by such a method because of its considerable variation in form and position combined with the high degree of damage and breakage displayed by some of the site assemblages.

Classification systems are a form of empirical research, i.e. interpretations based on observation. Attributes and variables are consciously selected and this process is conditioned by practical experience and intuition. The choice and relative importance of these may change with greater familiarity with the data set, perhaps due to unforeseen circumstances either in the nature of the material or in the objectives of the work. In the case of this study, the author had gained experience from the handling and recording of stone tools from Alderley Edge (Gale 1990) and a prehistoric mine site in Austria (Gale 1991; Gale & Ottaway 1990; 1991), as well as an acquaintance with material from a number of other European sites.

5.2 The descriptive system

More general details concerning the identification, location and documentation of individual items are presented in the foreword to the Catalogue contained on diskette, which also explains the format and convention of the record forms. The following sections are concerned with the background to the selection of descriptive attributes, and their form, order and method of measurement.

5.2.1 Condition

5.2.1.1 Tool form

This is the classification of the stone tool or part thereof according to the degree and form of damage and breakage it has suffered or represents. Each use-stage of the artefact is classified according to the following categories:

1) *Complete* - all size measurements are representative of the natural cobble.

2) *Incomplete* - this represents the 'used-up' state of a tool where its size has been reduced through use. More than half of the original cobble must survive and normally, by this definition, at least one of the axial dimensions is still representative of the cobble size. In some cases, only the weight may be affected by use-damage.

3) *Fragment* - a broken part of a tool which is less than half of the estimated original size of the cobble. Usually, all size and shape measurements are affected by breakage, but in some extremely fortuitous breakages up to two axial dimensions may be preserved. Roundness measurements may still be recorded for larger fragments.

4) *Spall* - a flake resulting from a single fracture event and which is smaller and thinner than a fragment. Scratch hardness and rock type are the only absolute properties that can be recorded. It is possible that a small portion of the original cobble's surface will survive, but only limited information about the surface texture, such as the degree of smoothness, can be derived from this.

5) *Core* - a stone so considerably reduced by usage that little or none of the original surface of the cobble survives. The exact type of natural facet exploited through use, i.e. end, edge or face, cannot, normally, be identified. All the size dimensions are classified as 'damaged' (see below).

6) *Broken core* - as above, but where at least one of the axial dimensions is classified as broken.

5.2.1.2 Surface condition

This heading covers surface conditions which result from natural agencies occurring prior to and after use of the stone, e.g. weathering, barnacles and staining, as well as those arising during their employment as tools, e.g. heat treatment. Weathered surface forms include exfoliation, i.e. onion-like flaking of the surface, and cracking. Weathering is usually manifested by a softer, lighter coloured, surface.

Many of the stone tools from the Great Orme are coated in calcite and, more rarely, encased with flowstone. According to Dutton (Dutton *et al.* 1994), the fine calcite coatings found on many of the stones from the Type 3 deposit (prehistoric mine waste) filling surface workings are formed by ground water percolation particularly where the spoil is immediately adjacent to bedrock. Thick coatings are found on stone tools removed from underground contexts during modern mining activities.

5.2.2 Natural Form

Natural form covers the physical and morphological properties of the cobble. Laboratory experiments and carefully controlled field studies have shown cobble morphology is a function of the following: 1) the initial shape of the liberated rock fragment, controlled by the geological structure of the parent rock, 2) the mineralogical and internal characteristics, e.g. hardness, brittleness etc., and anisotropic properties such as bedding, schistosity, and jointing, of the rock itself which will dictate its degree of resistance to abrasion and chemical weathering, 3) the size of the particle, 4) the form and intensity of weathering, 5) the degree of chemical corrosion and mechanical abrasion that has occurred during sediment transport, and 6) the effects of post-depositional processes (Sneed & Folk 1958; Fisher & Bridgland 1986). Sedimentologists have studied clast morphology as a means of differentiating between deposits with the overall goal of palaeo-environmental reconstruction. Cobble shape cannot be used in this study to identify stone tool sources because of the human factor in their selection. These recording methods can still be used, however, to record the natural form of the cobble and examine the morphological parameters involved in their selection in relation to their function. These involve the measurement of size, shape, relative roundness and surface texture, all of which are a measure of the degree and form of abrasion undergone by the cobble. In addition, certain surface marks and features resulting from abrasion can be used in a limited number of cases to identify cobbles from different sources.

5.2.2.1 Rock type identification

The identification of rock types for rounded cobbles is particularly difficult without recourse to thin section petrology. Even grouping rock types into general classes, such as extrusive igneous, plutonic igneous, sedimentary and metamorphic (Pettijohn 1975, 161), can be problematic.

For the Welsh site assemblages, part of the material has been identified by their respective fieldworkers, whilst a more limited number of identifications have been made for the material from Alderley Edge by thin-section petrology (part of the CBA implement petrology programme) and surface examination (courtesy of Geoff Gaunt, University of Bradford).

5.2.2.2 Degree of scratch hardness

Hardness is a property which measures the resistance of minerals and rocks to abrasion. This is most commonly determined by using a scale of hardness devised by the German mineralogist Mohs in 1812, sometimes referred to as the 'scratch test'. He arranged ten minerals in increasing order of hardness, so that each would scratch the one below in the scale but not the one above (Correns *et al.* 1969, 111). It would appear that Mohs selected the minerals very carefully in order that he achieved equality in the intervals (Tabor 1954). The degree of hardness of an unknown mineral is tested by observing whether or not a point or edge of minerals on Mohs's scale, or objects of known hardness, scratch a smooth surface of the unknown. The scratch test can be used for rocks, indicating the hardness of constituent minerals as well as the degree of cohesion of mineral grains. As most rocks contain a range of minerals, a range of hardness values is, therefore, possible. Objects of known hardness used in this study were as follows; the fingernail - 2½, two-pence piece - 4, steel knife blade - 5½, and a steel file - 6½. With rocks, the scratch test only works effectively on smooth, unweathered, surfaces, otherwise grain relief or softer weathered products are removed thus giving the impression of a scratch and resulting in an erroneously low value. To guard against this, the smoothest part of a cobble was selected and the sharp edge of the object was drawn heavily across the surface. If rock flour was produced this was wiped away and if a true scratch had been made this would still be visible. For stones suspected of being surface weathered a second comparative scratch was made on a fractured surface.

The maximum hardness value for rocks, such as quartzite, is given as 7 as this is the value of quartz.

5.2.2.3 Size

The size of rock particles can be expressed in terms of dimensions, weight and volume. It is most usual for the size analysis of lithic material to be based on length. Length can be defined in one of two ways: either as the maximum length or as the working length. (There may be a significant difference between them as illustrated for flaked flint by Morvius and Brooks 1971). Ideally, the working length should be measured but for these particular recording purposes the maximum length was considered to be more appropriate. This is because errors would be introduced using the former method where unworked cobbles are to be included and where studies of cobble sources are to made.

Sedimentologists, on the other hand, are concerned with the hydraulic behaviour (i.e. settling velocity) of rock particles over a much greater size range, and they express size as a diameter or radius equivalent to that of a sphere of quartz. This is most commonly represented by a two-dimensional measure of the 'nominal diameter' which is defined as the diameter of a circle with the same area as the particle's plane of maximum projection (Pettijohn 1975, 27). Axial dimensions are regarded as adequate expressions of particle size, although weight and volume measurements (which are more accurate expressions) are not normally used.

The main advantage of using length as a size measurement is that it is not affected by damage and breakage to the same degree as weight and volume would be. Length is shape related, however, as a disc and a sphere with the same length, for instance, will have very different weights. Weight, therefore, is a better expression of cobble size. For these reasons both weight and length are recorded, the procedures for which are described below and in section 5.2.2.4 respectively. These are measured for all tool states so that damaged and broken pieces can be allocated to size classes based on undamaged measurements, where appropriate, and so that the size of recycled pieces can be studied in relation to the available source material.

Measurement of weight. Weights are obtained on site and in various museums using kitchen scales for material under 5kg (measuring to +/- 25g) and using a Salter dial spring balance for material over 5kg which measures up to 25kg with an error of +/- 50g. The material held by the National Museum of Wales is measured using an electric balance (Salter FV-60K) which measures to +/-10g to a maximum of 60kg. In the field, artefacts over 25kg are weighed using bathroom scales.

5.2.2.4 Shape

The description of pebble shape can be considered in terms of two concepts: geometric shape or form mostly on the basis of the three axial measurements, and a measure of relative roundness or angularity which is described separately in section 5.2.2.5. There is a third category of particle form expressions, which is not appropriate to this study, devised by sedimentologists in order to describe dynamic behaviour rather than particle geometry (e.g. Flemming 1965).

Numerically based shape descriptions measure three dimensional size rather than actual shape and, as such, will be unable to differentiate between a cube and sphere. As it is recognized that certain environments can produce distinctive shapes, for example, the faceted forms of certain ventifacts (stones shaped by wind-blown sand) and glacial cobbles, there have been attempts to use shape classes based on regular geometric shapes (Holmes 1941; Wentworth 1936). As most cobbles do not conform to discrete geometric shapes, this method has had limited application. In the case of cobble tools, certain shape forms may have had an important bearing on the selection of cobbles, therefore, both geometrical and numerical methods of shape description are used. These are described separately below.

Geometrical shape description. As noted above, classifications based on regular geometric shapes are unsatisfactory. Flemming (1965) has suggested an alternative method by counting the number of corners for the pebble. For cobble tools, this method is extended to include edges and faces for each level of use for the cobble. For example, a disc will have one edge and two faces, and a blade will have two edges, two faces and two ends. Most cobble tools are ellipsoidal/ovoidal and tend to have elliptical or tabular cross-sections, suggesting two to four edge and face components. Thebault (1966) found that this ellipsoidal shape tendency in pebbles is universal, being independent of lithological and sedimentary condition. No true spheroids, i.e. solids having no ends, edges or faces, have been encountered. Since cobble tools are often damaged and broken several levels of recording are necessary: firstly, surviving shape components of the natural cobble, and secondly, shape components formed through use-damage. Further levels are used to record shape components arising from damage and breakage through reuse. These additional levels of recording are necessary in order to account for the loss of natural shape components and to define the form of the tool through each stage of employment and discard. No attempt is made to reconstruct the original form of broken cobbles.

The shape of the cobble's faces is also an important factor as, for example, flat and concave forms are more suited to anvil and mortar working. Their form may also have a bearing on the need for and type of modification for hafting. The shape of cobble faces are accordingly classified as convex, flat or concave. These forms are also related to the degree and type of abrasion undergone by the cobble.

It is possible that certain shapes or edge forms may have influenced the need for, or form of, haft modification (Craddock & Craddock unpublished) and that for these reasons specific shapes may have been preferentially selected by the Bronze Age miner. Unfortunately, as the proportions of hammers modified for hafting are either very small or large, it is not possible to undertake this type of shape analysis.

Numerical shape description. Numerical shape expressions are mostly based on the three axial dimensions, the measurement of which are described below. These expressions fall into two groups: indices denoting relative sphericity or circularity, and indices expressing concepts of form such as flatness, elongation and skewness.

The term 'sphericity', the degree to which a particle approaches the shape of a sphere, was originally defined by Wadell (1932). He devised a number of expressions for its measurement (Wadell 1933; 1934; 1935) of which the formula based on the axial dimensions proved most popular. This has been superseded by the 'maximum projection sphericity' (Sneed & Folk 1958), which is again based on the three axial dimensions. It is a better discriminator between oblate and prolate forms. Later on, Dokins and Folk (1970) devised a prolate-oblate index which has been widely accepted.

Graphical methods of shape presentation based on the axial dimensions are commonly employed and these include schemes designed by Zingg (Pettijohn 1975, 54), Sneed and Folk (1958), and Dobkins and Folk (1970). Numerous other indices, many incorporating forms of roundness measurements, have been proposed (for a summary see Dackombe & Gardiner 1983, 124-6; Goudie 1990). A number of workers have devised indices of asymmetry and skewness (Cailleux 1945; Flemming 1965) based on the measurement of displacements in symmetry of the stone but these have proved to be unpopular. These measurements are found to be impractical due to the difficulty of defining the plane of the axis to a precise and unique position, particularly for parallel sided and irregularly shaped cobbles.

Axial measurement and classification. The three principal diameters or axes, namely length, breadth and depth, are usually measured as mutually perpendicular intercepts without a common reference point. Although size measurement of pebbles and cobbles based on axial ratios has been extensively used, very few researchers have applied rigorous procedures to particle orientation and measurement. Krumbein's procedure (1941) is only acceptable for ellipsoids and ovoids. For the purpose of this research a method based on Griffiths (1967, 121) is employed as follows:

1) Establish the plane of maximum projection.

2) Find the minimum width in a parallel plane and take this as the intermediate diameter (b axis).

3) The long diameter (a axis) of the particle is measured perpendicular to the intermediate diameter.

4) The longest intercept across the particle normal to this plane forms the short diameter (c axis).

In the past a number of methods have been suggested to measure pebble size. Cailleux (1945, 381) used a board with concentric graduations while Krumbein (1941) recommended a sliding rod caliper. In order to fulfil the orientation definition, the author devised a measuring box which allows both the long and intermediate axes to be measured simultaneously. In order to obtain accurate measurements, the lengths were offset from the edge of the cobble to the graduated board by a set square.

It is important in later data analysis, to differentiate between those measurements that are representative of the natural cobble size, those which have been reduced through use-damage or broken. Destroyed axial dimensions are classified as 'broken' and 'damaged' where they have been reduced through use so that it cannot be regarded as representative of the original size, but may reflect discarded or 'used-up' size.

5.2.2.5 Relative roundness

The relative roundness of a cobble is a measure, independent of shape, of the degree of abrasion and it is, therefore, related to the degree of surface smoothness or 'polish'. Solution weathering also contributes to this rounding process but to a much more limited degree, and its affects are most noted in the rounding off of angular projections (Stapert 1976). The rounding of clasts will improve their mechanical strengths on two accounts. Firstly, angular projections are sites of weakness under load as they present low contact areas which will result in high contact uniaxial stress and hence greater susceptibility to brittle fracture. Secondly, small flaws in the rock, sites of fracture initiation and propagation, will tend to be preferentially removed by abrasion.

Wentworth (1919) originally introduced the term 'roundness' as the ratio between the diameter of curvature of the sharpest corner to half the longest diameter. This was later to be adopted by Cailleux (1947) and has become known as the Cailleux Roundness Formula. This has been widely employed although it is a measure of circularity rather than true roundness. Wadell (1932) refined the definition by proposing that the total roundness was the ratio of the arithmetic mean of the roundness of individual corners to the radius of curvature of the maximum inscribed sphere. This is a time consuming method designed for enlarged two-dimensional images of sand grains which, for convenience, is normally calculated on the plane of maximum projection. For larger sized particles, it has now been largely superceded by the Modified Wentworth Roundness (Dobkins & Folk 1970) which is the diameter of the sharpest corner divided by the diameter of the largest inscribed circle. The measurement of the latter is made more difficult for larger sized stones by virtue of the parallax. As a short cut, several workers have produced charts for the visual estimation of roundness which have been measured by the Wadell method (Powers 1953; Krumbein 1941; Pettijohn 1975, 57).

In the context of this study, damage to cobbles through anthropogenic use means that roundness values based on an arithmetic mean are of limited use, particularly since the smallest corners have the most effect on the roundness value. These are normally the ends of the cobble which are most often damaged through use. A visual assessment of roundness is found to be most useful because it can estimate the roundness of damaged cobbles. Two numerical measurements of roundness based on minimum diameters of curvature are also taken. These methods are described in detail below.

Visual roundness. This is estimated by using enlarged images from the chart devised by Krumbein (1941); a method of making a two-dimensional estimation of pebble roundness for the plane of maximum projection. The chart contains ten sets of standard images for roundness values from 0.1 to 0.9 (fig. 5.1). Roundness values for broken, rounded, pebbles were determined by estimating the roundness of the unbroken portion and then dividing the roundness value by two, rounding down half-class values.

Numerical roundness measurements. The minimum diameter of curvature in the plane of maximum projection of the cobbles, denoted as 'Dk', is recorded where possible. In addition, the minimum curvature in the cross-section (plane of minimum projection) of the cobble is recorded, denoted as 'Dxs', as this part of the cobble is least affected by use-damage. These curvatures are measured by using a set of cut-out plastic templates to accommodate curves up to a maximum diameter of 300mm. Templates with the following diameter of curvature are used: 2, 4, 6, 8, 10, 15, 20, 25, 30, 35, 40, 50, 60, 80, 100, 120, 140, 160, 180, 200, 220, 240, 260, 280, and 300mm.

5.2.2.6 Degree of surface smoothness

Although the degree of abrasion is recorded in the shape and roundness, the overall 'smoothness' or 'roughness' of the pebble or cobble surface has not been used by clast lithologists as an index of abrasion. In general the degree of smoothness will be determined by the mineralogy, grain size and physical properties of the rock. Fine grained xenomorphic

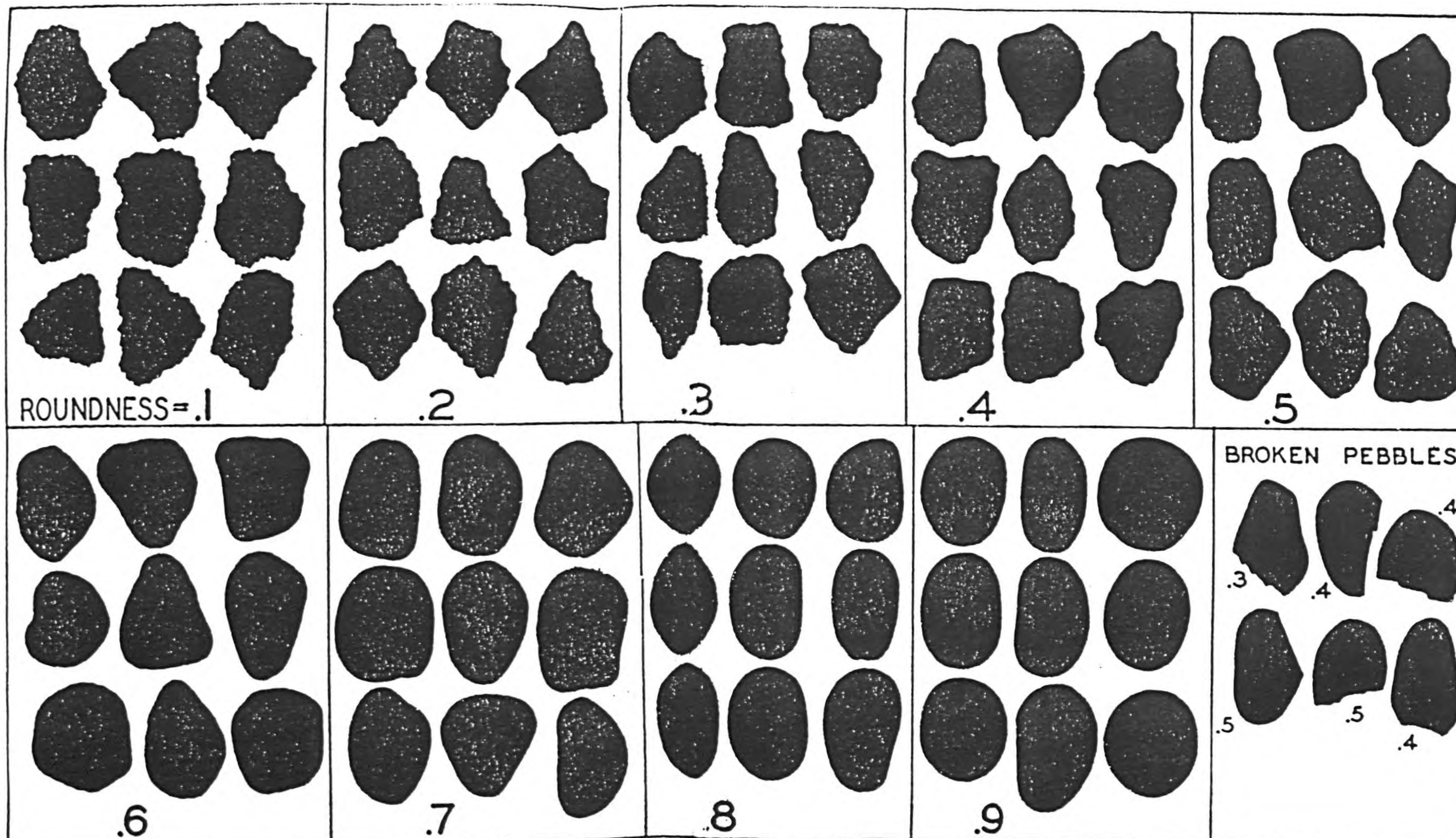


Figure 5.1 Krumbein's (1941) visual roundness chart.

igneous rocks will be readily polished, whereas rocks which are weakly bonded or contain an assemblage of minerals of different hardness are resistant to polishing (Gerrard 1988, 87; Knill 1960). Although smoothness is closely related to roundness, a separate classification of surface smoothness is important in five respects: 1) rocks resistant to polishing can, nevertheless, become well-rounded through abrasion, 2) some fine-grained rocks can be readily polished without becoming well-rounded, 3) a range of smoothness scores for a single item will record partially healed natural breakages, which are not reflected in the roundness index, 4) surface smoothness improves the mechanical strength of clasts due to improved intergranular bonding of surface grains by the removal of grain relief. This decreases the proportion of unbonded to bonded surface areas and means that the stress concentration zone under compression will be enlarged (Gerrard 1988, 179). For rocks, this property is only important for the contact surface (Obert 1972, 104). Lastly, 5) the degree of smoothness will determine the grip ability of a haft or hand, and perhaps influence the type and degree of modification.

The following ranked class states were used to record the degree of smoothness:

1) *Low* - rounding of higher-relief grains.

2) *Medium* - partial removal of grain relief.

3) *High* - complete removal of grain relief and partial removal of interstices.

4) *Very high* - polished finish, no trace of interstices.

More than one state may be recorded as some stones may exhibit evidence of several phases of breakage and abrasion. Mineral and anisotropic variation, for example bedding, within the stone can also result in differences in smoothness.

5.3 Surface texture

The surface texture of clasts, i.e. minute surface features or microrelief, reflect their abrasional and post-depositional history. Most studies of surface textures have been related to sand grains using optical microscopy and scanning electron microscopy, with the aim of identifying ancient sedimentary environments. Certain features, such as striae and pits, however, are readily visible to the unaided eye but these have been studied in much less detail. Work involving archaeological material is also of limited value to this study as this has been restricted to fissile rocks, such as flint, chert and limestone, in order to distinguish between natural and human flaking.

Markings resulting from abrasion are quickly imparted or erased from the surface of the particle during transport. For example, Wentworth (1922) determined experimentally that glacial striations on limestone pebbles would disappear after transport in a river for only 0.35 miles without a significant change in pebble shape. The implication for this research is that a high degree of certainty can be attached to stone tools that are striated as being derived either directly from a glacial deposit or a fluvial source very close to one such. Most other distinctive marks, for example chatter marks, slickenside striations, 'pitted' and 'cupped' pebbles (Pettijohn 1975, 63), are restricted to either specific rock types or rather exceptional conditions which are not relevant to this study. Surface features produced by wind abrasion are also particularly distinctive but they are only found in the Alderley Edge assemblage.

Although some surface textures are symptomatic of, or commonly associated with, specific sediment types, most clasts are generally rounded and indistinct. It should also be appreciated that many cobbles have already been modified in earlier sedimentary environments. This means that most stones derived from glacial and periglacial deposits will be indistinguishable from those obtained from fluvial and littoral sources by their surface texture alone. The description of surface texture, therefore, contributes only limited information on the sources of cobbles that were exploited by the prehistoric miner.

The recognition of common yet undiagnostic marks is, however, very important as these can be confused with marks resulting from use-wear and modification, especially since these are found predominantly on the edges/sides and the centre of relatively flat faces of pebbles (Dobbs 1958 cited in Dobkins & Folk 1970). The description of surface texture is divided into three sections: the first dealing with marks associated with glacial and periglacial sediments, the second describing forms produced by wind abrasion, and the third detailing general marks resulting from attrition. The presence of these marks is included in the recording procedure.

5.3.1 Surface features produced by glacial and periglacial processes

5.3.1.1 Striae and scratches

Striae are most commonly associated with glacial action and, less importantly, drift ice (Wentworth 1936) and snow-slides (Dyson 1937). Scratches have been attributed to soil movement processes (Clarke 1914; Sharpe 1938), most notably under periglacial conditions (Stapert 1976). Obviously, where large blocks are involved, striae comparable to those produced glacially can result. Similar linear surface marks can also be produced by differential chemical weathering of joints and cracks, and finely bedded sedimentary rocks.

Glacially striated material is produced as a result of abrasion in the tractional zones of the glacier. Striated clasts are found to occur in flow, melt-out and lodgement tills (Boulton 1978). The extent, size and pattern of glacial striae are dependent on the lithology and the fragment-bed contact forces. Although some patterns, for example parallel striae, have been observed to occur in specific till deposits, it has not been possible to link particular striae patterns to till types.

The width of striae reflect the size of the contact area exerted by an asperity of a colliding rock fragment which is sufficiently strong to support the load and to resist crushing

(Hallet 1979). The clarity of striae is dictated by the properties of the rock: hard, fine-grained, rocks with good cleavage exhibit very fine and well-developed striation patterns whilst soft, coarse-grained or brittle rocks do not take the markings well. Wentworth (1936) recorded that only one to ten per cent of stones were prominently striated. Large and furrow-like striae are known as 'grooves' (Embleton & King 1975, vol. 1, 183) and these may measure several centimetres in width. Striae grade down in size to very fine marks which are not visible to the unaided eye. Abrasion by silt-sized particles (rock flour) produces a general polish. Glacial striae may vary in form; they usually develop and end gradually but they may start or finish abruptly in a blunt, sometimes fractured, end in a form known as a 'nail-head' (Pettijohn 1975, 63). They are usually straight,although curved forms occur less commonly and, on rare occasions, they may be stepped sideways in an *en échelon* pattern. The sides of the striae are usually smoothed but chatter marks, crescentic outcrops punctuated by almost vertical fractures, can occur for some rock types.

The shape of rocks picked up by the glacier through plucking and frost weathering will be angular as they fracture along joint and bedding planes. Other stones, for example those in meltwater streams in advance of the glacier, will be well rounded before becoming incorporated in the till. These rounded stones will tend to roll as a result of traction in the glacier bed which will produce superimposed sets or facets of striae (Boulton 1978), giving rise to grid and random striation patterns. Platy clasts, on the other hand, will tend to slide rather than rotate, which will produce striated faces with parallel and subparallel patterns aligned with the long axis of the clast, and the faceted shapes noted for glacial cobbles.

Care was taken to distinguish between glacial striae and surface linear marks produced by chemical weathering. The former tend to be better defined with the removal of grain relief from the channel, whereas those produced by the later process are shallow with polished grain relief, occurring only in parallel patterns aligned with structural features such as bedding, which override changes in surface relief.

Scratches ascribed to periglacial soil movements, gelifluction and cryoturbation, have been considered to be mainly randomly distributed with occasional sub-parallel sets. Stapert (1976) described these natural scratches as being 'segmented' as they appear to have been produced intermittently. A similar observation was made for flint by Reid Moir (1914) which he attributed to variations in the hardness of the flint. Glacial striae have, on occasions, been observed by the author to show segmented forms, however, the pattern of segmentation appears to be irregular. A number of other causes may be suggested to explain this phenomenon: the accumulation and release of stress, or where the shape or size of the striator means that it is unable to make contact with the hollows in the surface of the rock which is being striated (Hallet 1979).

5.3.1.2 Stoss-and-lee sides, and snub scars

Glacial stones can also be distinctively moulded and fractured. Boulders and cobbles can form miniature *roches moutonées* where they protrude from ground moraine giving rise to the classic stoss-and-lee form, i.e. a smoothed, bullet-nosed up-glacier end and a truncated, or 'plucked', down-glacier end (Boulton 1978; Krüger 1979). The form of the stoss-and-lee sides or ends is controlled by the structure of the rock relative to the direction of the ice, variables which may give rise to particular marks and fracture patterns.

Stoss-ends may be similar in form to radial pressure flaking, described as snub scars, of debris held in the tractional zones of a glacier. These are flake scars, both in the edge and end of the stone, which have been struck or 'pushed off' from the face (von Engeln 1930; Wentworth 1936). These commonly form concave facets, exhibiting a low degree of surface smoothness.

For this study, the term snub scar was employed to cover all forms of edge/end flaking characteristic of glacial action.

5.3.1.3 Facets

The faceted shape, i.e. many flat sides, of many glacial stones, had been recognized many years prior to Von Engeln's often quoted paper of 1930. In this, he suggested that initial primatic and cubic rock fragments would evolve 'flat iron' shapes through the process of glacial abrasion. Wentworth (1936) vindicated this description and found that 'well-shaped', i.e. faceted, cobbles were much more common than the occurrence of snub scars and striations, although the exact incidence of the former varied considerably according to rock type. His observations suggest that facets are rarely produced solely by glacial abrasion. Flat surfaces formed by bedding, jointing or fracture are preserved as they slide rather than rotate once incorporated in the bed of the glacier and prominent striae may result (Boulton 1978; Holmes 1960).

5.3.2 Surface features produced by aeolian action

5.3.2.1 Ventifacts

Ventifacts are rock fragments which have been abraded by wind blown sand, usually in arid and proglacial environments. They are characterized by highly polished surfaces (see below), and faceted shape forms and other etched surface features (Cooke *et al.* 1993, 292). These facets are produced on the windward side of a stone at surface through sand blasting. Multiple faces are formed by changes in wind direction or in pebble orientation, and ridges are formed both between facets and the unabraded surface (Sugden 1968). Ventifacts have been divided into three shape forms: 1) discoids, 2) ridged ellipsoids with two opposing facets, and 3) pyramidal forms with three or more faces. The abrasion of inhomogenous rocks results in the preferential etching of sites of structural weakness, for example banding, phenocrysts and vesicles, to produce raised or incut features such as pits, grooves, ribs, cusps and flutings (Cooke *et al.* 1993, 294).

In this study, stones of these forms are found in the district of Alderley Edge where they are associated with quaternary drift and conglomeratic facies (the Helsby Sandstone Formation) of the Triassic rocks (Thompson and Worsley 1967). In north-east Cheshire up to fifteen percent of pebbles in Permo-Triassic horizons yielding ventifacts, show evidence of wind abrasion (Thompson 1991). Some quaternary specimens exhibit both glacial and aeolian abrasion, while others are undoubtly of Permo-Triassic origin which have been much fluvially abraded.

5.3.2.2 Gloss

Aeolian sand abrasion produces a glossy or frosted surface known as 'wind gloss' (Pettijohn 1975, 62). This is associated with small pits which are thought to have been produced by mechanical or chemical processes (Stapert 1976). It is distinguished from fluvial polish by its lustre and greasy appearance. Although features of desert weathering have been reported for pebbles contained in Permo-Triassic rocks similar to those occurring at Alderley Edge (Tucker 1974), other surface textures similar to wind gloss, glazed or vitreous coatings known as 'rock' or 'desert' varnish (Cooke *et al.* 1993, 48), have not been reported.

5.3.3 Other natural surface marks and features

5.3.3.1 Pits

Surface pits form through a process of chemical weathering of minerals whereby alteration products (secondary minerals) have been removed, either in solution or through abrasion, to leave cavities. Chemical decomposition usually results in the breakdown of intergranular bonds through grain alteration which then allows the harder mineral cores to be abraded from the rock surface. The rate of this process will depend on crystal size, shape and perfection as well as chemical composition. Structural features, such as joints, cracks and bedding planes, are also sites of preferential weathering as they allow water to penetrate the rock. This form of natural surface modification has been observed by Stapert (1976) in relation to Middle Palaeolithic flint finds from the northern Netherlands.

5.3.3.2 Bruise marks

These are minute, undetached, fractures produced by low level attrition which give the surface a mottled appearance. These are associated with highly polished surfaces.

5.3.3.3 Chink marks

These are small superficial pits produced by higher impact attrition than bruise marks, which gives rise to rock flour rather than chips or flakes. They are also sites more readily attacked by chemical weathering, and pit marks may be formed as secondary features. Chink marks are smoothed and gradually erased by lower-level attrition. They are found to be most developed in high energy streams and rivers, and storm beaches. Chink marks are most prominent on the edges and ends of pebbles and cobbles and, to a lesser extent, in the centres of flat faces. As the edges and faces of cobbles are also sites for use and haft modification, which are, of course, produced by a similar action, the recognition of chink marks is very important (see section 5.4).

5.3.3.4 Plate scars

This is a new category created during the course of this study to encompass scars which have resulted in a small step-like termination along the edge of a flaw or joint. Unlike flake scars, these may be produced by more than one impact event. They are, essentially, macroscopic versions of the plate-like features observed for quartz sand grains (Blatt *et al.* 1980, 76). Plate scars are the most common form of mark, occurring in most environments, and these have probably been classified as chatter marks or flake scars by other workers in the field.

5.3.3.5 Flake scars

Flake scars or 'percussion marks' result from the chipping effect caused by the collision of pebbles against each other and the rock-bed, a process known as attrition, in high velocity fluvial and littoral environments. These range in size from very small chips to fairly substantial flakes. They are particularly common for fissile rock types such as chert and dense quartzites. A study of the damage to pebbles from a range of gravel deposits by flaking and fracture, however, would suggest that only a small proportion are affected - in the range of 2 to 7% (Mason 1965). Identical marks can also be produced by glacial action and mass movement (Oakley 1975). With fine grained rocks, flake scars may take the form of a cone of percussion.

5.3.3.6 Fracture

These surfaces result from the process of splitting whereby two subequal fragments are formed. Fractured surfaces are recognized by angular margins to relatively fresh and unabraded surfaces. Highly water-worn cobbles which have become broken are most commonly called 'broken rounds'. In many cases the reported breakage of pebbles in rivers and on beaches refers to chipping, impact scars, rather than actual splitting. For rivers this is confirmed by archaeologically based studies by Clark (1958) and Harding *et al.* (1987) in relation to flaked tools, the former suggesting that the fracture of cobbles by other agencies, such as rockfall, would appear to be more important. Factors contributing to the fracture of river pebbles are: 1) the velocity of the river or stream, 2) the lithology of the pebbles, 3) presence of waterfalls, and 4) nature of the channel bed (Kelly 1983).

It is also necessary to include this surface texture category for the purpose of describing those stones which had been obtained by breakage, through quarrying for instance, or shaped by flaking rather than being directly derived from sediments.

5.4 Use-wear

Use-wear is the physical manifestation of a task performed on some other object or substance. Where pebble, cobble and boulder tools are unshaped the macroscopic form this use takes is used to classify the material into functional descriptive types. For the most part these type groups are based on intuition, and empirically based classifications by replication are exceptional, although there have been a few attempts to substitute specific use-wear forms in the place of traditional functional categories (e.g. Gorman 1979). Workers have become more aware that differences in the form and position of use-wear may be related to the physical properties of the stone. For example, in the case of a stone hammer the position of working will be related to the force of impact required for the task being performed. It follows that the contact force will be dictated by the weight of the stone and the shape or, more specifically, the curvature of its surface. Factors such as these have generally not been taken into account for most tool classifications.

At a macroscopic level, use-wear features rather than marks are used in stone tool classifications. Microscopic use-wear analysis has had only a very limited contribution to functional discrimination and type description (e.g. Adams 1988; Dodd 1979). Microwear analysis of stone tools has much less potential than for microcrystalline rocks. This is because the assemblages contain a broad range of rock types which display greater structural and mineralogical variability. In the case of coarser grained material, abrasion will result in grain removal rather than wear marks. Stone tools are, therefore, unsuited to microwear analysis.

As cobble tools are simple and culturally undiagnostic in comparison with chipped stone implements, forming only a small part of the stone tool assemblage, there have been few formal attempts to examine how different wear patterns are formed and to what extent these can be used to identify working techniques. Wear patterns can be considered in terms of the following parameters:

1) *The working area* - a task will be performed by first selecting a particular part of the cobble, the end, edge or face, for its property of surface roundness or flatness.

2) *Use-marks* - certain uses, depending on lithology, may produce distinctive marks, e.g. grind marks, and polishing.

3) *Use-wear facets* - although the use-marks may not be indicative of a particular use, facets may be produced which reflect either the form of the worked object or the way in which it had been worked.

For pounding actions, the striking force of a hammer will depend on the contact area. The smaller the radius of curvature of the end used as the contact or working area, the more concentrated the force. The edge of a stone, on the other hand, will deliver a more diffuse blow than its end, since it will have the benefit of a greater radius of curvature in the plane of maximum projection. By increasing the surface area of contact, for example by tilting the end of the stone so that the blow is no longer perpendicular to its surface or in other words 'offset' from the point of minimum curvature, the impact is reduced. In some cases this 'offsetting' may produce distinct facets if the tool has been held consistently in this position, and these are directly related to the optimum force required for the task performed. For example, pecking hammers used in stone working exhibit faceted ends because the hammer has been used at an angle of about 60 degrees to the surface in several or more positions

(Ranere 1975; Patton 1991). These facets normally occur in pairs and ridging develops between them thereby producing a gable-shaped profile. Offsetting and faceting are by no means confined to pounding stones, and similar working features have been identified for grinding and polishing stones.

Flaked stone tool specialists recognize the difference between flakes struck by 'hard' and 'soft' stone hammers, and that hammers are initially hard and become soft through use (Ranere 1975). This is because initial pounding produces impact pits, resulting in dust or 'rock flour' and very small flakes, which have relatively high relief and sharp edges. With use, the ridges between impact pits become erased resulting in a much smoother surface, described as a 'soft' facet. The size and form of these impact pits will vary according to the lithology of the stone and the material against which the stone is used. Similar soft facets can be produced directly by the pounding of softer substances, wood for instance, or finer and more angular materials, for example in crushing rock fragments.

Heavier use will result in flaking and, possibly, fracture. Similar breakages may occur for rocks employed for lighter uses, hard or soft hammers for instance, which contain inherent weaknesses such as jointing and bedding. Where stone hammers exhibit flaking and fracture with little or no evidence of impact pits from lighter use surviving, this would suggest a heavier, battering, function.

It is possible, therefore, to make a rough distinction between the relative intensities of use for stone hammers. At the lighter end of the scale, a certain degree of specialization can be detected both from the use-marks and the form of any faceting. O'Brien (1994, 131) has classified the breakage of stone hammers in terms of the number of axial dimensions surviving intact. Fragments and spalls were categorized according to the plane of fracture (transverse and longitudinal) and whether the surfaces were flaked or the naturally abraded surface survived.

It should not be forgotten that natural abrasion may produce seemingly identical marks and surface textures, and that glacial striae and natural polish are most commonly mistaken for evidence of anthropogenic use. Natural surface marks are, on the whole, evenly distributed and graduated, identically weathered and smoothed by natural abrasion. Use-wear marks, on the other hand, are fresh in appearance, rougher to the touch and confined to specific areas of the cobble.

Natural fracture surfaces are generally readily distinguishable from fractures resulting from use-breakage because of the wearing down of grain relief and the rounding of the fracture edge by natural abrasion. In a similar way, natural abrasion marks, such as chink marks, are smoother to the touch than use-wear impact pits. Glacial striae are more irregular in shape and form than anthropogenic grind marks and, normally, the surface of the facet is not sufficiently flat or regular to have been produced by manual grinding. Although glacial striations are mostly confined to a particular face or edge of the cobble, marks often spill over onto other parts of the cobble. The identification of anthropogenic polish is more difficult because similar forms of faceting produced by changing the position/hold of the stone during use are also formed by wind abrasion.

5.4.1 The use-wear recording procedure.

5.4.1.1 Phase of working

Use-wear is recorded for each phase of use of the stone. Reuse was defined as a re-employment of the tool core or fragment after breakage, characterized by either remodification or use of these fractured surfaces. A damaged tool is not considered to have been re-employed unless this is associated with a change in its form or use. The following terms are adopted to describe the phases of use: primary - the initial or first use, secondary - the first reuse, and tertiary - the second reuse.

5.4.1.2 Shape form position

As the function to which the stone has been employed has dictated the position of working on the cobble in relation to its shape relative to its size, i.e. its relative curvature or flatness, use-wear is classified according to its natural shape form, i.e. end, edge and face. For damaged and fragmentary pieces, where the original shape of the working area cannot be determined, the term 'indeterminate' is employed. Each position exhibiting use is recorded in the order of ends, edges and faces as defined above in 5.2.2.4.

5.4.1.3 Presence score

The number of working areas for each shape position of natural shape form is recorded numerically, i.e. 1, 2, 3, etc. Multiple areas of working are obviously located on the edges and faces of the cobble in general.

5.4.1.4 Detailed shape form

Although the position of the working area is classified according to its natural shape form, this does not describe the shape in any detail. Certain shapes may have been preferentially selected while others may have been ill-suited to the use to which they were employed. In order to record the particular shape of the working area the following classification is employed: convex, concave, flat, point and edge. The term 'edge' is used to describe an end which has a sharp margin in only one plane. The term 'flake edge' is introduced for reused pieces in order to describe sharp or angular margins produced by flaking and fracture.

5.4.1.5 Use-wear marks and features

The following forms of macroscopic use-marks have been observed and their presence are recorded:

1) *Grind marks* - fine, parallel, striations which may form composite patterns. They may occur within a distinct facet defined by ridged edges.

2) *Striae* - these are similar to grind marks though these are not as regular as they have been produced individually and not in sets.

3) *Scratches* - these are similar in form to striations, except that they graze, rather than score, the surface of the stone.

4) *Polished striae* - this consists of usually fairly fine and polished striae set back from the working area in a radiating pattern. These marks are confined to stone hammers from Alderley Edge and are produced as a result of working soft sandstone. In coarser grained rocks polished ridges are formed between striae by the crystal relief.

5) *Polish* - a very smooth surface, perhaps with a dull sheen, for which no use-marks can be observed.

The remaining types of use-marks result from pounding functions which demonstrate the hardness of the material worked, the force of the pounding in relation to the physical properties of the stone, and the resilience of the material and manner in which the stone was held:

6) *Bruises* - these are small superficial marks produced by the crushing of grain relief which results in minute, undetached, fractures. Where a fracture surface has been worked, it is slightly smoothed and mottled in appearance.

7) *Very soft pounding* - this is characterized by minute impact pits which are smoothed and polished.

8) *Soft pounding* - these are small impact pits which have low and smooth grain relief. More intense working produces an even smoother surface with little evidence of pitting. These marks equate with the flint knapper's 'soft' hammer.

9) *Hard pounding* - these impact pits are larger and more pronounced than those produced by soft pounding, with higher relief. Intense working may result in a 'softer' surface through the removal of grain relief. These marks equate with the flint knapper's 'hard' hammer.

For these forms of pounding, the impact crushes the contact surface of the stone and produces a small quantity of rock flour. Harder impacts, which result in brittle fracture, will also produce an impact pit, but this will be either partially or completely lost with the detached flake. The size of flaking increases with the force of the blow (Warren 1914), therefore the size of the flake scar can be used as a guide to the heaviness of use of the hammer.

10) *Severe pounding* - this is a halfway state for which both processes of crushing and fracture are involved, producing irregular, flaked pits. This normally occurs on the faces or broad edges of hammerstones or the ends of coarse-grained rocks.

11) *Flaking* - at an individual level these are not large enough to significantly alter the form of the working area. Two types of flake scar may be recognized, depending on the nature of the rock and the direction of the blow in relation to the morphology of the contact surface. A 'feather' termination has been defined as a flake with a thinning edge, whilst a 'step' or 'hinge' termination is used to describe an abrupt right angle break which thereby forms a step.

12) *Fracture* - this is a flake event which is substantial enough to alter the form of the working area, perhaps damaging one of the axial measurements or causing the cobble to be classified as 'incomplete'.

13) *Breakage* - this is a fracture event which results in breakage and the formation of two or more subequal fragments so that the cobble is no longer serviceable for the task for which it was being employed. Where the cobble has broken into two pieces of which one is larger than the other, an 'incomplete' tool piece may be formed.

Flaking and fracture will reduce the mechanical performance of the cobble. A fracture may dramatically reduce the size or form of the tool, thereby making it redundant, whilst multiple fracture or breakage may totally destroy the tool.

The occurrence of brittle fracture will depend on the force of the impact relative to the mechanical properties of the stone. Even for heavier duty tools fractures may not result from every blow due to factors such as variations in the striking force, contact forces and the striking angle. This means that most stone hammers which have been heavily worked will exhibit hard pound marks as well as flake scars. Flaking is also associated with well-developed pounding due to the reduction in its mechanical performance. This results from reduced intergranular bonding between surface mineral grains, after the removal of the smoother natural surface of the stone, and crack initiation and extension through continued use. The broadening of the working area through the reduction of the stone's surface also means that the edges of the working area become more susceptible to flaking due to the greater impact force as the striking angle becomes more perpendicular and the greater stress gradient. It is for these reasons that pounders possessing broad working areas of soft to hard pounding marks also frequently exhibit flaking. It becomes clear that ore-dressing and ore extraction functions cannot be identified solely on the grounds of the presence of particular use-wear marks/damage and that other factors, such as the type and degree of use-wear, and the physical properties of the stone, may lead to different wear patterns.

It is also possible for fracture and breakage to occur at sites on the tool other than the point of impact, for instance, at the opposite end to that being struck, by a process of flexial and axial vibration (Tsirk 1979) known as 'lateral snap'. This occurs at points or planes of weakness, and rock types possessing anisotropic properties, such as bedding and foliation, will be most susceptible.

5.4.1.6 Intensity

It has been noted by other workers that a large part of some site assemblages was discarded in a serviceable state (Lewis 1990a; O'Brien 1994, 129f). One way of categorizing tool consumption is to classify the degree to which the tools have been used. This also allows comparisons to be draw between tool types. O'Brien (1994, 132) employed three descriptive classes to categorize the degree of use for each worked end in his study of the Mount Gabriel material: light, medium and heavy. For this study, four classes of use intensity are employed and these are defined as follows:

1) *Scant* - marks which appear to be use-wear, but occur in such few numbers that there is doubt as to whether the stone has been utilized. It is possible that some of these marks may have been produced naturally or by post-depositional processes.

2) *Trace* - limited use that has removed little of the stone's cortex.

3) *Minor* - use which has started to change the form of the stone's surface or to produce more developed working forms (see section 5.4.1.10).

4) *Major* - intensive working which may have altered the overall shape of the working area or which may extend over or affect a significant part of the stone.

5.4.1.7 Position

As noted above, stone tools may have been employed either perpendicularly or offset to the working surface. These states are recorded as 'normal' and 'offset' respectively.

5.4.1.8 Roundness

This records the original natural roundness of convex working areas by measuring the maximum and minimum diameter of curvature using the method described in section 5.2.~~1~~2.5. These are denoted 'Dmax' and 'Dmin' respectively.

5.4.1.9 Worked shape form

Some functions, depending on type and intensity, will change the shape of the cobble surface. Convex surfaces may be reduced to a flat or waisted surface through grinding or pounding, and, similarly, the pounding of flat faces may produce concavities. The amount of reduction necessary to produce a change in the natural surface form will be dictated by the mechanical properties of the stone and the roundness of the working area. A broader edge will require a much greater degree of reduction than a narrow one in order to change the shape form of the working area, either through damage or by a specific use-wear form.

In order to record these changes in the shape form produced through use, the resultant shape of the working area is recorded using the terms defined in section 5.4.1.~~7~~4

5.4.1.10 Working form

This variable describes the pattern of the use-wear or the form of facets developed through use. The following more general form types have been identified:

1) *Simple* - this is used to describe the most common type of working which is concentrated in a particular area but does not show faceting or other more developed forms of working. Flaked and fractured working belong exclusively to this class.

2) *Scatter* - this term is appropriate for random marks which are not concentrated or centred around a particular position on the stone. The description is usually applied to bruises, striations, scratches and pound marks on the face or body of a cobble.

The following classes are employed to describe forms produced by grinding, polishing, and, for the most part, pounding:

3) *Stria* - a linear feature formed by soft/hard pounding.

4) *Dimple* - a small hollow produced by soft/hard pounding. This may occur as an isolated piece of working or within areas of more extensive working.

5) *Continuous* - the even working, i.e. without gaps, of an edge, usually produced by pounding.

6) *Discontinuous* - intermittent working of an edge, again usually as a result of pounding.

7) *Circumferential* - this is the working of an edge formed where the end of the cobble is flat.

8) *Notch* - a concavity produced by flaking which would suggest the heavy hammering of a sharp object.

9) *Faceted* - more intense and controlled working of a single area resulting in a pronounced edge to the working area and a change in the shape form of the cobble surface.

More developed types of faceted working have been identified as follows:

10) *Indented* - a hollow or shallow notch formed by concentrated pounding at one place.

11) *Dual-faceted* - offsetting in both directions in one plane thereby producing two associated facets, separated by a ridge or angle.

12) *Triple-faceted* - offsetting in one plane to produce three associated facets.

13) *Ridge-faceted* - this type of working is associated with ore-dressing and takes the form of ridging around the edge of a pounder.

14) *Double dual-faceted* - offsetting in both directions and in both planes to produce four radiating ridges. Sometimes the dual working in one plane is more developed than the other and the smaller facets are then divided by a central ridge. These features are normally ascribed to pecking hammers.

The remaining classes are employed to describe mortar facets:

15) *Compound* - a form describing a slightly pronounced internal cupping.

16) *Dual compound* - a rarely occurring form where a mortar facet contains two internal cuppings.

5.4.1.11 Measurements

1) *Size of work facets* - for certain work facets, normally the pounded concavities found on the faces of stones, measurements of diameter or length and breadth, and also the depth are taken. For broken mortars, the radius rather than the diameter is recorded.

2) *Extent of continuous and discontinuous edge pounding* - the proportion of the edge which has been worked, expressed as a percentage of the circumference, is measured by using a flexible strip of plastic. This is only appropriate for tools which did not have end shape components.

3) *Depth of flake scar step terminations* - a rough measure of the size of flake scars can be made for those scars terminating in a 'step' by measuring the depth of this step. As a flake scar can on occasions have more than one step, giving the impression that more than one flake has been detached, only the depth of the outline termination was determined unless a separate point of impact could be identified. In order to standardize the procedure, the depth at the centre of the step was measured perpendicular to the surface unaffected by the flake event under determination by vernier callipers.

5.5 Modification for hafting and handgripping

The form of modification divides into three types of working:

1) *Superficial pounding* - patches of surface pounding resulting in a roughened surface. Where these occur on the face of the cobble it has been suggested that they were used to hold wedges which were inserted to tighten the haft binding or that they are simply damage resulting from these being hammered into place (Craddock & Craddock in press).

2) *Notch* - deeper working of the edges of the cobble or other small ridges to form a notch to seat a haft binding.

3) *Groove* - a band of continuous pecking encompassing part or all of the stone, which may be superficial or in the form of a deeper 'groove', in order to seat a haft binding.
The division between pecking and notching is made according to depth, where measurements of greater than 2½mm are classified as notches.

Haft modification is found in three progressive positions relative to the shape of the stone which have been divided into two groups, 'transverse' and 'lateral'. The latter, comprising two positions, is confined to material from the Alderley Edge assemblage.

Transverse modification is positioned medially to the two ends of an ovoid cobble in a crosswise direction to the force of a blow to one of the ends. Lateral modification is found only as an extension to the transverse form, cupping the butt (the opposing end to that being worked) of the stone. This is normally positioned across the faces of the stone but further lateral modification has sometimes been made around the edge of the butt. These positions are distinguished by the terms 'face' and 'edge' respectively. As laterally modified hammers exhibit a lower degree of breakage than those with only transverse modification (Gale 1990), a high degree of confidence can be placed in their identification.

The evidence for haft modification, in the case of grooves and notches, should be obvious. The distinction between use-wear and modification, however, is not so clear cut for the material from the Welsh mine sites. In order for areas of surface abrasion to be classified as transverse haft modification the following criteria should be met:

1. The position of working should be relative to the central circumference of the plane of minimum projection and roughly at the centre of gravity of the cobble. Where more than one area of working is present, these should be aligned at right angles to the long axis of the cobble.

2. The work marks should show evidence of soft/hard/severe pounding and small flaking. Scratches occurring on their own are not deemed sufficient evidence for modification; they

are, however, incorporated in the use-wear recording system.

3. The area of working must be discrete and well defined. Large areas of working and 'scatter' patterns are not considered.

The polishing of grain relief identified for these working areas is thought to indicate wear by the haft.

In many cases, the distinction between use-wear and modification remained unclear, and inconclusive classifications are indicated by inserting a question mark after the tool type name. The situation can be made more difficult where modified tools have been re-employed, especially if they are broken.

5.5.1 The recording procedure

Modification is classified according to the phase of use of the tool and the haft modification by its position in the following order: transverse, lateral face, and lateral edge. To achieve consistency in the recording procedure, so that the positions of different types and phases could be related, an orientation rule for the hammer has been devised. The stone hammer is positioned with the most heavily worked end to the left, and with the most intensively/extensively modified edge to the top or, in the absence of edge modification, the modified face upper-most.

5.5.2 Haft modification

5.5.2.1 Transverse modification

Superficial pounding and notches. This is divided into 'edge' and 'face' positions, based on the shape components defined above in 5.2.2.4. The number of pieces of modification are recorded for each individual shape component in order, according to the orientation of the stone hammer. The type of use-marks (as defined in 5.4.1) and the intensity of working are recorded in an identical manner to that employed to record use-wear. The degree of polish is recorded according to the scale of 0 to 5 where:

0 - none.

1 - trace.

2 - polish of grain relief.

3 - removal of grain relief.

4 - partial removal of interstices.

5 - removal of interstices.

The diameter or, alternatively, the width, and the depth of each area of modification are measured. For notches, the shape of the cross-sectional profile is also recorded. Four type classes were recognized: superficial - shallow and undeveloped, U-shaped - steep sided with a relatively flat bottom, concave - having a smoothly curved profile, and V-shaped. The position of each working area relative to the long axis, denoted as 'Lm', is also measured because there is sometimes evidence of more than one binding.

Grooves. The type of use-marks are again recorded, as well as the degree of polish (a range of values are possible which reflect differential wear by the haft binding), and the cross-sectional profile of the groove. (For class types see 'superficial pounding and notching' above.) Groove types are categorized as:

1) *Complete* - a groove completely encompassing the midriff of the cobble.

2) *Incomplete* - a groove which is almost complete, save for one small gap in working.

3) *Discontinuous* - a groove which encircles the cobble but exhibits more than one gap. Gaps are normally caused by irregularities, e.g. hollows, in the cobble's surface.

4) *C-form* - a groove which encompasses both edges but only one face of an oval cross-sectioned cobble.

5) *Face* - a short length of grooving confined to a single face of the cobble. This may be 'offset' to the edge, thereby encompassing the more curved part of the face.

6) *Edge* - a short length of grooving confined to the edge of the cobble. This may be 'offset' in a similar manner to the 'face' type. This positioning is most appropriate to edges that consist of a flatter or less rounded portion bounded by more pronounced corners.

7) *J-form* - a continuous groove encompassing one face and one edge.

8) *U-form* - a continuous groove which encircles all of the cobble's midriff except one edge.

9) *Damaged* - this class, as the name suggests, is devised solely to account for broken and damaged pieces which could not be attributed to one of the above types.

The following measurements are taken where appropriate:

1) The position of the groove relative to the long axis, again denoted as 'Lm'.

2) The maximum width and depth of the groove.

5.5.2.2 Lateral modification

Face modification. Lateral face modification is defined as being positioned in the plane of intermediate projection of the cobble. Superficial pounding, notching and groove modification are recorded in this position using an identical procedure to that described for transverse modification above, adapted to the shape components of the stone in this position, normally two faces and one end. The following groove types were recognized:

1) *Complete* - a groove completely encompassing the butt of the cobble and joining the transverse groove on both faces.

2) *J-form* - a continuous groove extending from the transverse groove on one side and encompassing the face and the end.

3) *U-form* - a continuous groove which is complete except that it does not join up with transverse groove on both sides.

4) *End* - a small length of groove which encompasses only the end of the stone.

5) *Edge* - a small length of groove located over the edge of the butt away from the apex.

6) *Half* - a continuous groove joined to the transverse groove which encompasses half of the butt, i.e. one side of the end.

7) *Damaged* - broken or damaged pieces which could not be assigned to a specific class.

Edge modification. Lateral edge modification is defined as that positioned in the plane of maximum projection of the cobble. Again, the three forms of modification for this position are recorded using the procedure described above in 5.5.2.1, adapted to accommodate the shape components of this position, i.e. two edges and one end.

Only one form of groove modification has been identified. This is called a 'half' groove as it is a continuous groove joining the transverse and lateral face modification, encompassing half of the butt over its edge.

5.6 Introduction to tool types

Artefact pieces are classified into tool types as a means of describing their function and/or form. These tool types are formed in two ways: firstly by using descriptors, which can be combined, to denominate use types and more specific use forms, and secondly by a traditional classification which creates exclusive type categories through the use of real names for tools which are not conveniently described by the former method. Most tool pieces have been classified according to the descriptor system because, although they are relatively simple and undeveloped tools, they often exhibit variations in use and joint uses which are not mutually exclusive. The use of the traditional classification system is limited to either unusual forms or use-forms which occur in isolation.

Any form of descriptive categorization serves only as a guide to tool usages. Although the descriptor system allows more flexibility in the classification of tools that exhibit evidence of multiple use, including the ordering of use types according to their use intensity, this does not express the actual degree of use. The classification is not perceived to be exhaustive as new types may be recognized in further material or through more detailed re-analysis later in the study. One advantage of using the descriptor system is that it can facilitate the creation of new tool types by the combination of existing terms without, necessarily, having to invent completely new classes. Fragmentary pieces are indicated by suffixing the use type with the term 'fragment'.

All material is classified according to its initial use or uses, and subsequent recycled uses. Either classification system may be used for each use phase.

5.6.1 The descriptor system

Two types of descriptors have been used: use types which form the basic unit to which can then be added, if appropriate, the specific use terms. The descriptors are defined below. Use type descriptors can be divided into two categories: uses related to both the cobblestone core and pieces thereof, and those exclusively related to the recycling of tool fragments and spalls.

5.6.2 The Descriptors

5.6.2.1 Use types

1) *Hammer* - a stone exhibiting simple use as a pounder or maul. Unless otherwise specified, this takes the form of end-working and related edge-working.

2) *Mortar* - a stone with one or more cupped depressions resulting from the crushing action of a handheld implement.

3) *Anvil* - a stone whose face has been used as a crushing surface but which has not been sufficiently well-used to have developed a hollow which characterizes a mortar.

4) *Polisher* - the presence of polish use-wear.

5) *Pounder* - a small handheld stone which has a more developed form of working than the hammer. This may take the form of more continuous or faceted edge pounding or all over working.

6) *Grinder* - a stone exhibiting grind marks.

7) *Chopper* - a sharp fracture edge used as a crude chopping tool. Characterized by small, sometimes hinged, use-wear flakes which gives it a serrated profile.

8) *Tool* - a term used to describe a utilized stone piece for which a more specific function cannot be discerned. Most usually used in combination with the form type term 'fragment'.

9) *Spall* - a flake produced from a hammer (see 5.2.1.1).

5.6.2.2 Specific use terms

1) *Specialized* - a term used to denote a form of working which would suggest a function not directly related to ore extraction and dressing.

2) *Modified* - the presence of any features attributed to hafting or handgripping.

3) *Flake edge* - this term is used to denote the working of a sharp fracture edge of a recycled tool fragment or spall.

4) *Edge-worked* - a discoidal stone which has been exclusively edge-worked.

5) *Rounded* - a spherically-shaped stone which has been worked over its entire surface.

5.6.3 Specific tool types

1) *Cobbing hammer* - this is analogous to the modern Cornish cobbing hammer used in the dressing of tin ore. This is identical to the pounder except for the fact that the faces, or even edges, contain small dimples which have resulted from the crushing of small pieces of ore.

2) *Pecking hammer* - a small, ovoidal, pounder which can be held in one hand and which exhibits end faceting as a result of soft/hard pounding. This is normally associated with stone-dressing.

3) *Discs* - these are flat stones with a roughly circular outline produced by fairly regular working about their edge, which would suggest that they had been deliberately shaped.

4) *Pestle* - this is similar in size and form to the pecking hammer, but exhibits unfaceted end-use which is not limited to its apex. This would suggest, therefore, use in conjunction with a mortar.

5) *Rottenstone* - this is a highly decomposed but still coherent stone (Bates & Jackson 1987, 577). As they are soft and friable it is not always possible to determine whether they are stone tools or natural stones.

6) *Cobble* - this is a natural stone which shows no evidence of being humanly modified or worked, and whose presence at the mine site may not be accounted for by natural agencies.

CHAPTER SIX

Data Summary and General Observations

This chapter presents the breakdown of the individual site assemblages by tool types (tables 6.1) and describes general trends suggested by the data. The recovery circumstances and contexts for the individual collections which make up the assemblages are first examined in detail. This is in order to evaluate how representative the compiled site assemblages are to the true populations of the archaeological deposits. These considerations are important since biases in artefact recovery will affect the overall comparability of the site assemblages. General observations are then made concerning the tool type composition and frequency of the assemblages, and tool consumption. These trends are then discussed in terms of the dating and geological context of the mine site. The record forms for all the material studied, a total of 1010 pieces, are listed in the Catalogue (see diskettes).

6.1 Summary and comments on sampled stone tool collections.

6.1.1 Great Orme

A total of 391 pieces have been recorded, including 33 unused cobbles which are thought not to occur naturally on site. A table of the tool classes is presented in Table 1. The assemblage is made up of the following collections:

1) 296 items derived from the mechanical excavation of mine spoil in the vicinity of Vivian's Shaft during 1989/90. These were recorded on site and accessioned VIV 91 with a 9000 series number.

2) 26 items recovered during early fieldwork by James in underground workings in the Bryniau Poethion area (James 1988) which are represented by three figure GAT numbers.

Gwynedd Archaeological
They are held by the Trust in Bangor and the Snowdonia National Park Study Centre, Maentwrog.

3) 32 pieces from two manual excavations in the area of Vivian's Shaft, carried out by the Gwynedd Archaeological Trust in 1989. These are held by the Trust and they have VIV 89 accession numbers.

4) 7 pieces from the 1991 manual excavation of minor prehistoric trench workings to the west of Vivian's Shaft, supervised by the Gwynedd Archaeological Trust. These are accessioned VIV 91 with a 3000 series number.

5) 27 items were recorded from excavations underground in what is thought to be a prehistoric gallery known as the Flat Stope, near to Vivian's Shaft. These are numbered VIV 91.9704, and 9713-9738.

6) Three of originally four examples now held by Sheffield City Museum from the discovery of 'old-man' workings made in 1849 (Bateman 1855) have also been included.

There is a higher proportion of mortars in the collection recovered by James (a total of eight). Unfortunately, there are no details concerning their recovery but it would seem probable that these were collected at surface from the Old Mine. Dutton (1990) notes that both mortars and spherical pounders (described as pestles) have been found at modern surface level or within tips of mixed age, which would suggest that they are not associated with prehistoric extraction.

As a large proportion (76%) of the recorded material was recovered under watching-brief conditions during mechanical excavation, it is to be expected that tool fragments and spalls would tend to be missed and, thus, under-represented. Indeed, this pattern would seem to be supported by the type of material recovered during manual excavation. Unfortunately, since this latter material constitutes only 10 percent of the total assemblage an accurate evaluation of the degree of bias towards more complete specimens cannot be attempted. Although it has to be admitted that tool fragments and spalls are under-represented in this assemblage, the relatively high proportion of complete tools suggests that fragments and spalls will be few in number anyway.

6.1.2 Copa Hill, Cwmystwyth

A total of 380 pieces have been catalogued representing 376 stone artefacts, including a large hollowed stone. The assemblage is made up of the following material:

1) 155 items recorded in the field from the tip surface. This included 48 pieces previously recovered from the tip surface during the 1989 tip survey by the Early Mines Research Group. These had been left on site.

2) 12 items from Davies's excavation in the 1930s held by the National Museum of Wales. They consist of finds recovered from the three sections as well as the surface of the tips. Only more complete examples were retained by Davies.

3) 1 item recovered from the surface of the tips in 1984 which is held by the National Museum of Wales.

4) 115 items from the 1986 fieldwork season, also held by the National Museum of Wales, recovered from trenches D1 (a and b), C1 and A1 (see fig.4.4), and the tip surface (14 items).

5) 95 items from the 1989 fieldwork which are jointly held by the National Museum of Wales and the British Museum. The material has been recovered from trenches A2, C2, C3, C4, D2, D3 and D4 (see fig. 4.4), and the tip survey (17 items). A further single item was obtained from fill in the underground working directly beneath the opencast. 14 of the pieces held by the British Museum are undocumented.

The material recovered from the surface of the tips in 1986 and 1989 is biased towards less broken and damaged specimens and less common tool forms, most notably modified hammers and hammers also employed as anvil stones. By way of contrast, material from excavated contexts consists predominantly of hammer fragments and spalls. No differences in tool finds between trenches are apparent. A number of examples of more unusual tool types from the fieldwork in 1986 and 1989 were unavailable for study, and these include a mortar and a hammer also used as a grinding stone.

In summary, although the assemblage exhibits a high degree of reduction through use-breakage, it is biased towards more complete examples selected, in the most part, from surface finds.

6.1.3 Parys Mountain

The assemblage consists of 100 items mostly obtained from an area of prehistoric tip just north of Oxen Quarry. Three further items which were examined are interpreted as naturally occurring stones.

The assemblage is made up of the following collections:

1) 5 items from Site 3, trenches A and D, held by the British Museum.

2) 87 items from site 3, trenches A, B and D, and one item from Site 5 location Y (see fig. 4.6), held by the National Museum of Wales.

3) 2 items from the surface of the backfilled trenches at Site 3, held by the author.

In addition, a small number of items recovered at an earlier date were also studied as follows:

4) 1 item (grooved stone hammer) held by the British Museum. This was accessioned in 1878, along with another example (now lost) which was described as being 'found in old workings'.

5) 5 items held by the Museum of Welsh Antiquities, Bangor, which were recovered by Davies in the 1930s (Davies 1939). Three of these were derived from a section of the tip, while a stone disc and a hammer fragment were found at surface on the northern slopes of the Mountain.

The assemblage exhibits a high degree of breakage, being dominated by hammer fragments and spalls. Although not all the spalls and fragments were evidently recovered, the assemblage would seem to be more representative of the whole material surviving in these tip deposits than the collections obtained from the other sites.

6.1.4 Nantyreira

A total of 41 items from the fieldwork of the Early Mines Research Group in 1988, sites 1, 1A and 2, have been catalogued. Of these, 38 items are held by the National Museum of Wales and the remainder are with the British Museum. A mortar, possibly a bed from a mechanical stamp mill dating to the post-medieval period, was unavailable for study.

Incomplete stone hammers predominate over tool fragments and there are comparatively few spalls. The low recovery of fragmentary pieces may be explained by the very poor weather conditions experienced during the excavation.

6.1.5 Alderley Edge

A total of 95 items have been catalogued. These breakdown into the following collections:

1) 17 items held by the Grosvenor Museum in Chester. Three of the four stone hammers accessioned in 1910 as part of Dr. Clarke's bequest, are illustrated by Sainter (1878, 46 & 49), thus attributing them to the Brynlow site. Roeder and Graves's fieldwork is represented by a single item from their excavation of a mine pit (Pit III) at Engine Vein. The remainder are attributed to Alderley Edge in general.

2) 48 items held by the Manchester Museum. The main part of the collection is made up from material recovered by Dawkins from Brynlow in 1874 and Graves's fieldwork at the turn of the century. The material is attributed to the following areas: 14 to Brynlow, 3 to Engine

Vein - of which 2 were recovered in excavation, and 1 to Dicken's Wood. Of the 28 ascribed to Alderley Edge in general, 11 of these are described as 'probable' attributions, the reason for which is unknown. One item is of doubtful provenance. Two more recent acquisitions are, in fact, natural stones.

3) 2 items held by Warrington Museum for which no specific details are known.

4) 1 item held by Rossendale Museum ascribed to Alderley Edge.

5) 1 item held by the Transport and Archaeology Museum, Hull, recovered from the pit working at Dicken's Wood by Roeder and Graves (Sheppard 1914). Two further items, one from Brynlow and the other from Mottram St. Andrews, were mislaid at the time of my visit.

6) 6 items held by the Pitt-Rivers Museum which would have been recovered from Brynlow.

7) 4 items held by the Ashmolean Museum, which again would have been recovered from Brynlow in 1874.

8) 4 items held by Bolton Museum from Brynlow which were purchased from the Castleton Museum in 1888.

9) 7 items, currently held by the University of Bradford, recovered during recent fieldwork by the author. All the items were surface finds, 5 having been made in the area of Engine Vein and the remainder from Doc Mine, Stormy Point.

10) 4 items recovered as surface finds from Stormy Point, Engine Vein and Pillar Mine by members of the Derbyshire Caving Club.

In summary, 31 items can be attributed to Brynlow, 11 to Engine Vein, 7 items from the Stormy Point/Pillar Mine area and 44 items to Alderley Edge area in generally. All the material recovered by Roeder and Graves from the vicinity of Wood Mine and all but one of the items from Mottram St. Andrew, totalling 6 and 21 items respectively (Roeder 1901), have not been traced, although a number of pieces from Mottram St. Andrew were certainly retained by Graves (Alan Crossley pers. comm.; see also Roeder 1901). It is possible that a number of these pieces have become incorporated into that large portion of Graves's collection held by the Manchester Museum which is described as from Alderley Edge.

The assemblage is dominated by complete and incomplete stone hammers, and no spalls and few fragments have been recovered. It is conceivable that as the assemblage is composed chiefly of surface finds made by antiquarians, only more complete and clearly modified stone hammers have been collected while many broken pieces have been overlooked or rejected.

6.2 General observations on recorded material

The detailed breakdown of the stone tool assemblages by tool type, including reused (secondary) pieces, are given in table 6.1. Bracketed frequencies record uncertain or questionable class assignments, the pieces being allotted to more generic tool classes. It should be noted that although some tools show primary dual usage, these uses may not have been simultaneous and they may be no different from material classified as secondary except that the form of the tool has remained unchanged. This is illustrated by modified hammers which also served as ore-dressing tools, i.e. anvils and mortars.

All the assemblages are dominated by hammers which are, with a number of exceptions, end-type varieties. Other tool types which can be ascribed to ore-dressing, mortars, and small rounded and edge-worked pounders, are relatively uncommon except for anvils in the case of Copa Hill where they are moderately abundant. Stone tools that are not directly related to ore extraction, for instance, discs, polishers and other more specialized pounders and anvils, are rare. Some of these may be related to the preparation and maintenance of other mining tools and materials. Some of these functions may also have been achieved by using flake edge tools.

Tool type	Great Orme		Copa Hill		Parys Mountain		Nantyreira		Alderley Edge	
	First use	Second use	First use	Second use	First use	Second use	First use	Second use	First use	Second use
Hammers	262(7)	1	212	10(1)	36	1	28	-	6	3
Edge-worked hammers	11	-	1	-	-	-	-	-	-	1
Hammers with anvil working	17(1)	-	27(1)	5	1	1	2	-	-	-
Hammers with mortar working	-	-	1	-	-	-	-	-	-	-
Modified hammers	13(14)	-	16(20)	2(5)	3(11)	(1)	3(4)	-	79	8(1)
Modified hammers with anvil working	1	-	2(1)	2(3)	-	(1)	-	-	1	-
Anvils	6	1	-	34(1)	-	2	-	1(2)	-	-
Mortars	5	-	(1)	-	-	-	-	-	-	-
Mortars with hammer working	9	-	-	-	-	-	-	-	-	-
Hollowed stones	-	-	1	-	-	-	-	-	-	-
Pounders and cobbing stones	13	1	1	1	-	-	-	-	1	-
Flake-edge tools	-	13	-	58(1)	-	17	-	6	-	-
Tool fragments	5	-	9	-	1	-	1	-	-	-
Spalls	12	-	99	-	52(4)	-	5	-	-	-
Pecking hammers	2	-	-	-	-	-	-	-	1	-
Polishers	-	-	-	-	-	1	-	1	-	-
Discs	-	-	5	-	1	-	-	-	-	-
Specialist's tools	3	-	1	-	-	-	-	-	-	-
Modified cobbles	-	-	-	-	-	-	-	-	2	-
Unutilized cobbles	32	-	1	-	(3)	-	2	-	(4)	-
Rottenstones	-	-	-	-	6	-	-	-	-	-
Totals	**391**	**16**	**377**	**110**	**100**	**22**	**41**	**8**	**90**	**12**

Table 6.1 Site assemblages by tool type. Uncertain attributions are shown in parentheses.

The percentage of modified hammers has been calculated as a proportion of the combined total of all stone hammers classes. The resultant figure has a lower and an upper limit, the former corresponding to examples in which a high degree of confidence can be placed on their identification whilst the latter represents the inclusion of ambiguous assignments. For the Copa Hill assemblage specimens with secondary modification have also been included in the calculation so that the figures can be compared with an earlier study by Timberlake (1990c Fig. 9). The proportion of hammers exhibiting evidence of haft modification is relatively low for the Welsh sites and, by way of contrast, very high (93%) for the Alderley Edge assemblage. It is significant that only 8-20 percent of the total stone hammer component of the Copa Hill material has been classified as modified which is in conflict with an earlier study which suggested that as much as 60-70 percent of hammers showed evidence of modification (Timberlake 1990c). This higher figure was derived from surface finds only and the comparison with figures obtained for excavated material would suggest that it is too high. This may be in part due to sampling bias which has occurred either in the field or as the result of the selection of more interesting and complete specimens for museum collections. The author's study of a 25 percent sample of the original tip survey material demonstrates a modification rate of 13-36 percent, with few fragmentary pieces. The problem of sampling biases can be reduced by examining material recovered in its entirety, such as that from excavations in 1986 and 1989. In this instance, comparable rates of modification are obtained by the author and Timberlake, and an overall figure of around 5-10 percent is obtained.

These differences in the modification rates obtained by researchers highlights several problems. Firstly, the identification of haft modification where it is small in degree and ambiguous, as it is here, is more susceptible to differences in personal opinion. Secondly, sampling and recovery strategies will significantly affect the type and state of the material obtained. Thirdly, researchers will use different criteria for expressing the amount of haft modification as a proportion of an assemblage, and this will be a problem particularly where the material is fragmentary. For Copa Hill the author found that the modification rate for complete and incomplete stone hammers is 10-22 percent whereas for fragments it is 6-13 percent. This is to be expected as the identification of modification for fragmentary pieces can be impaired by breakage and the number of pieces bearing modification relative to those without will decrease resulting in under-recording.

The small cobbing hammers and pounders traditionally associated with ore-processing, including edge-worked and rounded pounders, have only been rarely recovered. These have been found most frequently at the Great Orme sites although their association with prehistoric spoil, as with the mortars, has yet to be demonstrated. For the other sites, it appears that ore was dressed by crushing it between the faces of stone hammers, designated as anvil stones, in a simple block-on-block fashion. These anvils were selected from hammers which had been either discarded as broken or were still in service. This would suggest that cobbles were selected primarily for use as mining tools and that qualities more suitable for ore-dressing were a later consideration. This is investigated in section 7.3.2.3. Very few examples have been worked sufficiently long enough to have developed the 'cupping' which would qualify them to be described as mortars. For the Great Orme assemblage, there is a small number of cobbles used solely as anvils. This can be linked to the lower pressure on use of stone tools which meant that it was not always necessary to recycle hammers.

The reuse of broken hammers, again as hammers, is relatively uncommon even for assemblages which exhibit higher reuse rates. Alderley Edge shows the highest proportion of recycled hammers although a small number of both modified and remodified stones have not been used. The extensive nature of the haft modification associated with stone hammers from this site means that reuse after breakage is more easily recognized since it is manifested by damage and repairs to the modification. This greater reuse of mechanically weakened stones can be linked to the soft nature of the ore deposit.

Copa Hill exhibits the highest proportion of reused stone hammers, and these are predominantly anvils. This high recycling pattern is confirmed by the appreciable numbers of spalls and fragments utilized as choppers, anvils and flake-edge tools. A similar trend is suggested by the Parys Mountain data where 30 percent of all spalls and fragments have been recycled. A high proportion of the very few tool fragments and spalls recovered at the Great Orme have also been utilized in this way.

6.3 Summary and inferences

The study is restricted to a small number of sites, and, due to the availability of material, weighted towards two sites in particular. It is clear, however, that the assemblages are dominated by mining tools and that tools specifically used for ore-dressing are poorly represented. The high proportion of recycled hammers used as anvils for Copa Hill suggests that ore-processing was, nevertheless, carried out at the mine. A high proportion of tool fragments and spalls were reused as flake edge implements, suggesting that they formed an essential part of the miner's tool kit. They may have been used in the preparation and maintenance of hafts, as well as for bone and wooden tools. Although hammers were recycled as anvils, it would appear that cobbles were selected primarily for use as mauls. The proportion of hammers which have been modified for hafting is small for all but the Alderley Edge site.

At this stage of analysis the tool composition of the site assemblages display little evidence of specialization or functional differentiation in the process of ore extraction. The use of anvil type ore-dressing tools suggests that comminution was a simple and relatively incidental stage in ore extraction, implying that only small amounts of ore were extracted for each mining campaign. It is possible that the combined use of stone tooling and fire-setting crushed and mechanically weakened the ore to the extent that it required less comminution than ore extracted at a later date by metal tooling. The method of contemporary ore-dressing at Great Orme is not so clear because, in addition to anvils, mortars and small cobbing stones and pounders have also been recovered although these may not be from prehistoric contexts. (Identical tools, however, are known for other European Bronze Age mining districts although these too suffer from a lack of direct dating.) It should be noted that a much longer period of exploitation at Great Orme is suggested by the C14 dates and that more specialized and labour intensive ore-dressing practices may have been adopted at a later date to extract harder chalcopyrite ores. Very small numbers of these tool types have also been recovered as surface finds from Copa Hill and Llancynfelin, as well as other mine sites unassociated with Bronze Age mining. These prehistoric mines also show later working, however, so it is possible that these tool types, including the hollowed stone from Copa Hill, are unrelated to Bronze Age extraction.

A gauge to the consumption and pressure on use of tools can be found in the number of spalls, the recycling of stone pieces and the quantity of unused cobbles. Many factors will be at work here, such as the availability of suitable cobbles, their lithology and the physical properties of the ore deposit. At a simplistic level of enquiry, the rate of consumption of stone tools can be explained by the hardness of the mineral deposit rather than by the effort of obtaining the necessary cobbles. Low breakage rates are exhibited by the Great Orme and Alderley Edge assemblages where the lodes are relatively easily worked. This is because the mineralization is contained within comparatively soft country rock. The higher breakage rates of Copa Hill and Parys Mountain are associated with harder lodes where the mineralization is contained within a matrix of quartz. These site assemblages also contain a higher proportion of ore-dressing tools.

CHAPTER SEVEN

Stone Tool Description and Analysis.

7.1 Introduction

This chapter presents the detailed description and analysis of the stone tool assemblages site-by-site (sections 7.2 - 7.6) and then in general (section 7.7). This involves the study of: 1) the natural form of utilized and unutilized stones, 2) the physical properties, morphology and use-wear of tool types, and 3) the form of modification for hafting hammers. Evidence for functional specialization both within tool types and between reused and joint used compared with parent tools, is examined. These results are then compared with the study of the Mount Gabriel material (section 7.8) undertaken by O'Brien (1994) and, finally, they are discussed in relation to the geology, cobble sources and mining techniques of the sites (section 7.9).

7.1.1 Notes on analysis

1) The ranked class-states used to record the degree of surface smoothness (section 5.2.2.6) have been recoded into quantitative multi-state characters as follows: freshly fractured rock fragment - 0, low - 1, low to medium - 2, medium or low to high - 3, medium to high or low to very high - 4, high or medium to very high - 5, high to very high - 6, and very high - 7.
2) Five shape indices are used in the analysis of cobble shape. These consist of the three axial ratios (b/a, c/b and c/a) and two roundness indices which are based on the breadth and depth of the cobble. Length measurements cannot be used because very few of these survive undamaged for the Copa Hill assemblage. The indices are as follows: 1) Kuenen's roundness formula (Kuenen 1956,) denoted as 'Rk', i.e. the diameter of the sharpest corner 'Dk' divided by the breadth of the cobble, and 2) the Cross-sectional Roundness Formula, denoted

as 'Rxs', which is the diameter of the sharpest corner 'Dxs' divided by the depth of the cobble (see section 5.2.2.5).

3) Two roundness indices have been used in the analysis of the shape of cobble ends which have worked. The indices are as follows: 1) the maximum diameter of curvature of the worked end, 'Dmax', divided by the breadth of the cobble, and 2) the minimum diameter of curvature of the worked end, 'Dmin', divided by the depth of the cobble (see section 5.4.1.8). These indices are denoted 'Rmax' and 'Rmin' respectively.

4) The presence/absence score of use-wear marks have also been recoded into quantitative multi-state characters by the conversion of their wear intensity classification, i.e. trace, minor and major, to give a scale, including the absence score, of 0, 1, 2 and 3.

7.2 The Great Orme Assemblage

7.2.1 Cobble form and condition

7.2.1.1 Rock types

Identifications have been made for 55% of the assemblage, a total of 215 items, of which 49 are unspecific or uncertain assignments (table 7.1). These consist of stones obtained from both Irish Sea and North Welsh tills but it has not been possible to distinguish between stones obtained from these two tills apart from a small number of rock types which are from particularly distinctive sources. The microdiorite and diorite rocks derived from Ordovician subvolcanic intrusions on the south-west side of Conway (Penmaenmawr together with the smaller plugs of Craig Fawr and Dinas), and transported by the North Welsh Ice-sheet, are an example. These form a large group, 28 altogether, reflecting a preference for medium-grained igneous rocks as well as pyroclastic rocks. Far-travelled erratics of the Lower Palaeozoic from the north of England and southern Scotland, such as gabbro, are further examples. Most of the basic and acidic volcanic rocks and sedimentary rocks are probably derived from Ordovician and Precambian rocks in Snowdonia. The Irish Sea till would have yielded few that would have been suitable due to its low content of generally small stones (Warren *et al.* 1984, 152). Local limestone cobbles were also utilized (fig. 7.6), but considering their great abundance (table 8.1) they were not often selected. As they are easily identified, the total number of identifications is representative of the whole assemblage rather than a proportion of the material examined in detail by rock type.

7.2.1.2 Surface textures

The frequencies with which natural surface textures and conditions occur are given in table 7.2. All but two of the catalogued items consist of cobbles; the exceptions, GOR.126 and GOR.390, consist of angular to subangular rock fragments. A small group of subrounded limestone cobbles, which are distinct from rounded to well-rounded ones (fig. 7.1 and 7.6), have also been identified.

Of the 391 cobbles which make up the assemblage, nine percent (34 cobbles) exhibit evidence of glacial abrasion (fig. 7.7 A to C). Glacial striae are mostly fine and faint, sometimes only forming light scratches, in scatter and subparallel patterns. Other forms, for instance nail-heads, are exceptionally rare. Snub scars are generally not very conspicuous and normally associated with striae and faceting. Glacially abraded cobbles, in general, consist of softer, finer-grained, rocks and, in cases where they are harder, far-travelled, coarse-grained rocks. Although they are similar in shape to the other cobbles, they are smaller and show a heavier degree of abrasion with less rounding (tables 7.3 and 7.4, and fig. 7.2). The difference between littoral/fluvial and glacial abrasive actions, i.e. rolling versus sliding, is also reflected in the form of the cobbles' faces (table 7.5). The minimum diameter of curvature of the worked ends of glacial cobbles are also significantly more angular than those of the other cobbles.

7.2.1.3 Unworked cobbles

Thirty-two of the catalogued stones show no evidence of having been worked. A number of these have been recovered from underground contexts, confirming that at least some of these cobbles were intended for use. It has been noted that they tend to occur in caches close to the mine face and floor (Dutton *et al.* 1994; Hammond pers. comm.) which would suggest stockpiling of fresh supplies. It is also possible that a number of these cobbles were derived from the thin layer of Irish Sea boulder-clay covering the site, becoming incorporated into the mine spoil through the course of mining operations. Only one unworked cobble, however, shows signs of glacial abrasion. Dutton *et al.* (1994) suggest that they may mark entrances to underground workings akin to Rudna Glava in former Yugoslavia.

Although unworked cobbles are smaller than worked ones, they show a similar size distribution to end-worked hammers (fig. 7.5). They are identical in shape and roundness to worked cobbles (table 7.6). This suggests that they were neither rejected due to inferior qualities after collection, nor naturally occurring on site. They show a greater degree of surface smoothness and scratch hardness which can be accounted for by the larger proportion of finer-grained igneous rocks.

7.2.1.4 Surface conditions

A high proportion, sixty percent, of the assemblage recovered from surface spoil, including unworked cobbles, are coated to some degree with flowstone. The three hammers recovered from the 1849 discovery are thickly coated (this severely restricts the recording procedure) and one of these (GOR.363) even contains fragments of charcoal and copper ore (or even, perhaps, corroded copper metal). By way of contrast, only eight percent of the material recovered from the underground stope are coated with calcite and this is in trace amounts. This would indicate that the spoil contained within the stope is not derived from modern reworking of prehistoric pack and would support the interpretation of the Flat Stope as a prehistoric working. The presence of flowstone is exceptionally rare for mortars, which may be seen to support the case for them belonging to a later period.

A small number of tools are iron-stained. This does not seem to be confined to any particular context or tool type, and it occurs with calcite coatings. A similar number of stones from surface spoil are burnt or fire-cracked (fig. 7.7D). They are generally small and consist of unworked cobbles as well as complete and broken tools. Heat treatment of hammers has also been observed by Dutton *et al.* (1994) who compares the level of discolouration with that produced by fire-setting. On one hammer (GOR.004), a small number of barnacles survive.

A number of stone tool pieces exhibited post-depositional damage, but these were remarkably few in number (1%) considering the degree of nineteenth century reworking of the mines.

7.2.1.5 General remarks

The majority of cobbles used as stone tools were undoubtedly obtained from the beaches surrounding the headland. The nearest and most accessible sources are to be found to the east at Llandudno Bay by the pier, and to the south and west from Conway Bay north to Gogarth Bay (fig. 7.4). For mining operations in the vicinity of Vivian's Shaft this would have involved a climb of 150m over a distance of at least three-quarters of a kilometre. Both areas contain Irish Sea and North Welsh Ice tills (Fishwick 1977). Pocket gravel beaches on the northern side of the headland are not readily accessible. The regional descriptions of the tills are given in Warren *et al.* (1984, 155) and Whittow and Ball (1970). There are also a number of local studies and descriptions, made in the later half of the nineteenth century, of coastal drift exposures (Binney 1861; Bonney 1867; Hall 1870; Stirrup 1882). Some of have now been obscured or destroyed by the construction of sea defences etc.

North Welsh Boulder Clay in this area, from the northern end of Conway valley, contains larger and more numerous pebbles and boulders, more especially of the Ordovician type (Warren *et al.* 1984, 149). Dolerite erratics, which are usually extremely rare, are abundant. Penmaenmawr-type erratics have been noted along the eastern side of Conway Bay (Bonney 1867).

Irish Sea Boulder Clay also occurs in thin patches within valleys and gullies on the higher ground of the Great Ormes Head (Lucy 1873; see fig. 7.4). It is possible that a small number of stones used as tools may, as a result of mining operations, have been derived from this. Binney (1861) describes a deposit of shingle, possibly a meltout gravel, which occurred close to the mines. If such deposits existed, they may have provided rich sources of cobbles once discovered.

The presence of barnacles on one hammer confirms that cobbles were obtained from beaches. These are found on stones at the mid-tide level (see Chapter Eight). Surface marks resulting from glacial abrasion are relatively weak which suggests reworking. This may have resulted from fluvial action during deposition or as a consequence of littoral erosion of coastal drift. Such stones can be obtained from the backshore of the beaches at Great Ormes Head. The division of limestone cobblestone tools into two distinct groups, namely subrounded and rounded to well-rounded stones, suggests that at least some stones were obtained from sources other than the beach. It seems most likely that the less rounded ones were obtained from surface drift, i.e. head and glacial deposits, at the mine site itself during the course of mining operations. There is a great profusion of limestone rocks contained in the mine spoil, so it is possible that larger numbers of these were employed as tools than has been recorded so far.

7.2.2 Description and analysis of tool types

7.2.2.1 Unmodified end-worked hammers

Size and shape analysis. Although end-worked hammers vary considerably in size (fig. 7.7, 7.9 and 7.10), ranging from several hundred grammes up to 29 kilos, they are dominated by small stones. Histograms of length and weight for undamaged hammers suggest that the distribution has two or perhaps three modes (fig. 7.5). Furthermore, a bimodal size distribution is also suggested by the data for hammers classified as 'damaged' in length and for unworked cobbles. This distribution is not shown by the beach cobble survey (fig. 8.2), and this would suggest that these size groups were the result of deliberate selection.

The proportion of cobbles with more than two ends decreases with size, reflecting the difference in the mode of use between single hand-held and two-handed or hafted hammers. Small sized hammers (0.25 to 1.5kg) also display a lower degree of surface smoothness than larger ones. This is explained, mainly, by the cobble type composition, i.e. the greater proportion of glacially abraded and subrounded limestone cobbles. Nevertheless, the selection of rougher surfaced cobbles for hand-held use, enabling them to be more easily gripped, may have been intentional.

Differences in shape between the various size modes have also been explored using numeric shape forms. Reliable differences between weight classes have been found using univariate comparisons of axial ratios and roundness indices. Full details of the results are not presented here as the degree to which the lithological composition of these groups contributes to the shape differences needs to be investigated in detail.

Use-wear analysis. One method of examining whether hammers show specialization in use has been to investigate the association between use-wear marks. This was achieved by calculating the Pearson product-moment correlation between pairs of use-wear marks using, as a data set, only complete hammers. The resultant correlation matrix is presented in table 7.7. (A similar result can be obtained using the chi-squared statistic for the unconverted presence/absence data except that it does not express the way in which the types are related.)

Severe pounding is, overall, more closely associated with the other types, suggesting that two use-wear groups are formed on the basis of its presence/absence: i.e. soft/hard pounders and heavier duty batterers. Very soft pounding shows significantly negative correlations with hard and severe pounding, and also flaking but is unrelated to soft pounding. This suggests that hammers with very soft pounding use-wear form a third group. The insignificant correlation with fracturing possibly reflects that inherent structural weaknesses may be a contributory factor to this type of damage. Differences in correlation between flaking and soft and hard pounding may be explained by a further physical property whereby the removal of the cortex, which occurs to a much greater degree by hard and severe pounding, makes the stone more vulnerable to flaking (see section 5.4.1.5).

This three group division of hammers is supported by examining the relationship between the cobble size and the dominant use-wear type (table 7.8 and fig. 7.8). Very soft pounders are larger in size than those solely showing signs of soft pounding. Very soft pounders are also characterized by broader worked ends than soft hammers. Hammers exhibiting hard pounding and associated heavier working are, in the main, much larger than those related to soft pounding, and coincide with the 6.25kg size mode suggested in figure 7.5. The division between soft and hard pounding therefore corresponds with the method by which the hammers have been used; i.e. small hand-held hammering and hafted/slung hammering. There is, however, considerable overlap in size between the groups and they show poor discrimination.

7.2.2.2 Modified end-worked hammers

The identification of haft modification was difficult since it is generally slight and, in any case, many end-worked hammers also exhibit other forms of edge-working (table 7.13). As relatively few hammers are classified as modified, detailed comparison of their form with other classes of hammers is consequently limited (tables 7.9 & 7.10).

Modified hammers mostly consist of igneous rocks with a scratch hardness of between 4 and 5½. They vary in size but no examples over 7kg are known. All but one are coated with flowstone. No examples have yet been recovered from underground contexts. They are not associated with any specific use-wear types and exhibit evidence of soft pounding through to fracture flaking. Various use-wear forms unlikely to have been produced by the effects of hafting, i.e. faceting and offsetting, are also recorded (table 7.11). They are not more intensely worked than unhafted forms and they may be worked at one or both ends (table 7.12). They appear to be similar in shape and form to unmodified hammers, except that their margins seem to be more rounded.

The modification consists of pounded patches and notches, generally shallow, on the edges and faces of the stone in the transverse position (fig. 7.11 and 7.12). Only rarely was more than one piece of modification necessary on one edge or face. Another feature which may relate to hafting is a line of pounding marks, 20 degrees to the long axis, on the one face of hammer GOR.138 (plate 2).

Specific shapes or edge forms, have on occasions, been selected. In one case (GOR.159) the natural edge notches (snub scars) of the stone, in conjunction with another artificial notch, have been enlarged to facilitate hafting (fig. 7.12B). In another example (GOR.355), the edge has been abraded either side of an edge projection (fig. 7.11B). Either this is a deliberate selection or a particular adaptation to this specific shape. A similar modification arrangement has been noted for material from the Brandergang mine site in Austria (Gale 1991).

Only one specimen is grooved (GOR.336), and this takes the form of opposing superficial edge grooves.[1] This is the only example to show any evidence of wear from the haft and manifests as a slight trace of polish.

7.2.2.3 Edge-worked hammers

These show a similar size range and use-wear pattern as end-worked hammers (table 7.10), being dominated by smaller examples. A massive limestone example (GOR.391), found in the Flat Stope, would have originally weighed more than 30kg. The hammers also cover a range of use-wear types but working forms, such as faceting, associated with pounders and cobbing hammers are generally absent (table 7.13). One unusual edge-worked tool, included under this heading, is a small pounder (GOR. 231) with flaking offset to one face as if attempts had been made to shape it (fig. 7.13B).

7.2.2.4 Mortars

These consist of igneous rocks, most especially Penmaenmawr-type microdiorite/diorite. They are ovoidal to discoidal in shape (average form ratio of 20:16:7), and weigh between three and twelve kilos. Over half show end/edge use which is, with one exception, relatively minor. One broken specimen has been reused as a hammer.

The mortar facets occur, with one exception, on both faces of the stone to a depth of up to 47mm (fig. 7.14 and 7.15). The work marks consist of soft to hard pounding, and cover the whole surface of the stone's face. In a few cases, the concave face contains a more pronounced cupping, which may not be centrally positioned, and, in one case (GOR.025), two cups have been formed. Other unusual features include a shallow, socket-like, recess, pentagonal in outline cut into the centre of the mortar cup of GOR.335 (fig. 7.15B), and the broad, fairly deeply incised, striae on the reverse side of GOR.111 suggestive of metal tooling marks.

7.2.2.5 Anvils

Stones used exclusively or predominantly as anvils are few in number (five). In most cases anvil-type working is combined with end hammering (table 6.1). A small number of substantial hammer and tool fragments have also been recycled for this use.

Anvils are roughly discoidal in shape (average form ratio of 10:8:5), with flat faces, and vary widely in size (from just over 1 to 15 kg). The use-wear marks consist of soft to hard pound marks and the working is, in all but one case, relatively undeveloped. Specimens bearing use-wear marks anomalous to this group are; 1) GOR. 072 which is worked by small striae, and 2) GOR.022, a hammer fragment reused with very soft pounding.

7.2.2.6 Pounders and cobbing hammers

These are small (less than 1.5kg), subspherical to discoidal stones (form ratio of 10:9:7). With the exception of a non-round (GOR.126; fig. 7.6C), they are well-rounded with broad edges and a high level of surface smoothness (fig. 7.13 A and D). Pounders predominate over cobbing hammers, although a number of the former possess undeveloped patches of facial pounding. They have been worked by soft to hard pounding which, in half of the cases, is faceted and consists of poorly developed double and triple forms. Circumferential ridging, or 'ridge-faceting', commonly exhibited by cobbing hammers from central European mine sites (e.g. Gale 1991), is present in only one example (GOR.074).

Two of the pounders were recovered from underground in the Flat Stope which suggests that ore-processing was not an activity restricted to the surface.

7.3 Copa Hill Assemblage

7.3.1 Cobble form and condition

7.3.1.1 Rock types

Rock identifications have been made for 71 pieces (22% of the total assemblage), the majority from material recovered during fieldwork in 1989 (see table 7.14). They consist of the local rocks, sandstones and sedimentary quartzite, of the Aberystwyth Grits Formation, which constitutes the sediment of the River Ystwyth and local streams. These can exhibit prominent jointing, cleavage and banding, and, on occasions, they can be described as flaggy. Cobbles containing quartz veinlets are not uncommon. As a consequence, some of the material would not have been particularly suitable for use as hammers. One exotic igneous rock has been petrologically identified and suggested to be provenanced to the Borrowdale Volcanic Series (Humphrey 1989) and another has been tentatively identified as a tuff. These can only have been derived from glacial drift deposited by the Irish Sea Ice, the nearest known source of which is located some 17 miles away on the coast near Aberystwyth. At this stage, with only one confirmed identification, it would be unwise to suggest that cobbles were specially brought in from the coast. Cobbles taken from the River Ystwyth would have had to have been carried up the one in three slope to gain the 250m in height to the mine.

7.3.1.2 Surface textures

The stone tools consist exclusively of cobbles, 10 percent of which are glacially abraded. Surface texture frequencies are given in table 7.2. Marks of glacial abrasion consist mostly of fine scratches and striae, snub scars and facets being few in number and, in the main, not associated with striae. Although glacially abraded cobbles are similar in visual roundness and facial shape, their margins are less rounded and they show a lower degree of surface smoothness (tables 7.15 and 7.16).

7.3.1.3 Surface conditions

A very small number of tools (1%) have been burnt and fire-cracked. Most surface conditions have resulted post-depositionally. A large proportion of the material found on the tip surface are covered with lichen which, on occasions, restricts the identification of use-wear, haft modification, and natural surface textures. A number of stone tool pieces are coated with ferri-mangiferous deposits. This includes tip surface material, suggesting that the stones have either been redeposited or disturbed. A very small number of stone pieces appear to have been post-depositionally striated and ground.

7.3.2 Description and analysis of tool types

7.3.2.1 Unmodified end-worked hammers

Size and shape analysis. The analysis of cobble shape and size for the hammers is made difficult by the high incidence of damage and breakage, undamaged lengths only accounting for 7 percent of the assemblage. Breakage is more common across the breadth and depth axes of the cobbles than the length, a pattern reflecting tensile fracture. A sufficient number of length measurements classified as 'damaged' have been made (140 or 38%), however, for some attempt to analyse hammer size to be made (fig. 7.17). The size distribution is approximately normal, with a small subsidiary peak occurring for the size class of 120 to 140mm which may relate to small hand-held hammers similar to those found at Great Orme.

Use-wear analysis. The data set for the measurement of association between the various use-wear marks is not very satisfactory due to the fragmentary nature of the tools.

Analysis has had to include all pieces except spalls. Use-wear marks are correlated in a stepwise pattern (table 7.18) which suggests that hammers belong to a single group even though lighter and heavier working do not tend to occur together.

7.3.2.2 Modified end-worked hammers

The identification of modification is not always clear cut as the areas of working are, in general, small and indistinct. Identification is further exacerbated by use-wear damage and breakage, and lichen cover. A small proportion of hammers (4% of both the primary and secondary material) also display small patches of edge and face working (~~fig.~~ table 7.13) which are thought to be unrelated to hafting.

Haft modification consists of superficial patches of pounding and shallow notches, located roughly to the centre of the faces and, more commonly, on the edges of the hammer. A small number of modified hammers show two areas of working at one of these positions, rather than the more normal single working, suggesting that they were hafted by binding several times with a broad material. Groove-type working is rare and only three examples, consisting of edge and face grooves, have been identified. Use-wear polish for all modification forms is, in general, either absent or minimal.

Striae on the face of one modified hammer (COP.146) appear to be related to hafting as their position corresponds to that of the edge-working. These are scattered at 45 degrees to the long axis of the cobble in both directions and vary in form from fine and shallow striae to broad nail-head and elliptical shapes. Two other, similar, occurrences of striae/scratches have been recorded (COP.079 & 134). It has been suggested that such marks may result from driving wedges into the binding in order to tighten it (Craddock and Craddock unpublished).

Morphological and use-wear data for modified and unmodified hammers are compared in table 7.17. Apart from the visual roundness data, which suggests that modified hammers may be rounded to a greater degree, modified and unmodified hammers seem to be identical in form. A comparison of the intensity of use-wear of the hammers' worked ends (table 7.19) suggests that modified hammers have been worked to a greater degree.

7.3.2.3 Anvil and mortar working

Anvil working is found in conjunction with end-worked hammering and is the most common form of stone tool recycling. One or, less commonly, two faces of the less damaged hammers and larger tool fragments were used. In general the working takes the form of light, undeveloped bruising and pounding. It is exceptionally rare to find more than one area of working on a face. Only four examples have been worked intensely enough to form very shallow hollows. This working is only sufficiently developed in one example (to a depth of 4mm) for it to be described as a mortar. By way of contrast, mortars from the Kingside workings, which are not associated with prehistoric mining, are larger and much more developed. The shape of these boulders predisposes them for use as mortars rather than end-worked hammers. One example, examined as part of this study, shows similar minor edge hammering to those recorded at the Great Orme (fig. 7.15C).

For the Copa Hill tools, the areas chosen for anvil working are, in the main, flat and concave faces. Fracture surfaces of laterally broken stones were preferred, although on occasions these were used to give the stone a stable base when working on the undamaged face. In only one instance was a naturally fractured surface exploited. There are no significant differences in morphology between cobbles used solely as end-worked hammers and those used/reused as anvils (table 7.20 and 7.21). Differences in roundness measurements probably reflect the fact that larger stone pieces were selected for anvil use (fig. 7.22).

The use-wear marks of most anvil facets suggest that they were used to dress ore, usually to quite a fine degree. A number of anvil facets contain scratches and striae in addition to pound marks. The character of these use-wear marks are discussed in more detail in section 7.7.3.

7.3.2.4 Other processing tools

Three tools have been recorded which probably date to later processing activity. These consist of a large hollowed stone (COP.333) and two stones used to hand-cob ore: a rounded pounder (COP.372) and a cobbing hammer (COP.143). The hollowed stone was recovered from the wall collapse of a drystone structure at Site A, located to the south side of the tip. It has been worked on both sides. Although the hollows are saddle-shaped and likened to a saddlequern, the work-marks are consistent with pounding rather than grinding.

7.4 Parys Mountain Assemblage

Stones used as mining tools cover a wide range of lithologies (table 7.22) derived from local Anglesey and Irish Sea Ice Boulder Clays, which include Carboniferous grit and chert, Pre-Cambrian quartzite and local intrusive igneous rocks (Timberlake 1990d). They show a similar pattern to the Great Orme material in the proportions of natural surface textures (table 7.2), i.e. a high proportion of low to high energy abrasion marks, indicating that they were obtained from a beach source. This is a distance of some three kilometres and a height difference of 140m.

The assemblage is dominated by stones with scratch hardness values greater than 6.5 and this is reflected in the high degree of surface smoothness (fig. 7.23). Rottenstones, giving scratch values of less than 2.5, would have been formed post-depositionally. Three of the stones examined (PAR.029, 097 & 103) have been interpreted as naturally occurring cobbles and have not been included in the assemblage. One of these even has a naturally formed groove.

Size data for hammers is restricted to a relatively small number of 'damaged' length measurements (fig. 7.23). They are smaller in size than those from Copa Hill but comparable with the ones from Alderley Edge. Larger-sized hammers undoubtedly existed because

Stanley (1873, 59), who saw the workings at first hand, described them as 'large boulders from the sea-shore'. Sykes's description of the hammers, 'all about 9 in. [230mm] by 5 by 3 thick, varying a little' (Briggs 1976), would seem to confirm that the present assemblage is not representative of original material even when taking into account their damaged state.

Haft modification is similar in form to the other Welsh assemblages. The single hammer recovered in the nineteenth century is the only example that possesses groove-type haft modification (fig. 7.24). The grooving, which is broad but relatively shallow, survives on the edges of the cobble and may have originally extended over one face. This form of modification is probably not unusual as Stanley (1873) reported notched and grooved forms.

The assemblage shows use-wear forms which are very comparable to the Copa Hill material (tables 7.23 & 7.24).

7.5 Nantyreira Assemblage

The stone tools consist of local Ordovician rocks (table 7.25), sandstones and sedimentary quartzites, derived from the Lower Van Formation (Timberlake 1990d). Although they show a comparable degree of roundness and surface smoothness (fig. 7.25), they possess a higher proportion of heavier abrasion marks (table 7.2) characteristic of a local stream bed source. The degree of roundness is related to size, smaller stones being more rounded than larger ones.

Due to the small number of artefacts and their high degree of damage, detailed analysis of the assemblage is not possible. A comparison to the Copa Hill material, however, can be drawn. The form and degree of use-wear (tables 7.23 & 7.24) and the damaged length distribution of hammers, as well as the haft modification working, are comparable.

7.6 Alderley Edge Assemblage

7.6.1 Cobble form and condition

7.6.1.1 Rock types and surface textures

The stone tools consist of local rocks, which include Carboniferous and Permo-Triassic sandstones, together with far-travelled rocks from the Lake District and southern Scotland (see table 7.26) derived locally from boulder clay. For details of the stone composition of the boulder clay see Taylor *et al.* (1963) and reports in the British Association for the Advancement of Science (Crosskey 1891; Kendall 1894; 1895). A high proportion of the stone tools, 54 percent in total, display marks of glacial abrasion with a correspondingly high rate of natural flaking and fracture (see table 7.2). Although the stones selected as tools are relatively well-rounded in outline, i.e. visual roundness, their shape and degree of surface smoothness belies a lower degree of abrasion (table 7.27 and fig. 7.28). The surfaces of a number of the tools are weathered, a characteristic of stones derived from the Irish Sea boulder-clay of the region (Ricketts 1885), which would have aided modification for hafting. The assemblage is dominated by rocks with relatively low scratch hardnesses (fig. 7.28), which also means that they would have been worked more easily.

A small number of stones, a few of which can be described as ventifacts, originate from conglomeratic facies of local Triassic rocks. These consist of pebbles of quartzite which are distinguishable from the other stones by their small size, highly polished surfaces and more rounded form (table 7.27). They are also more discoidal/spheroidal than the other cobble types. With one exception, which is modified, they form a group of small hand-held hammers. There are a similar number of larger stones with wind gloss which are thought to have formed during the Quaternary. Three possible sources for both these cobble types have been identified by Thompson and Worsley (1967): 1) the Permo-Trias surface, where it is drift free, 2) the upper surface of the Stockport Formation (Quaternary drift), located to the east of Edge House (SJ 866775), and 3) late and post-glacial alluvial sands on the north-western flanks of the Edge (SJ 848779).

Three stones (ALD.029, 063 & 064) are interpreted as naturally occurring cobbles unassociated with mining activity. One of these was recovered during the earthwork survey in the area of the Engine Vein Fault to the west of the Engine Vein Openwork. It had originally been thought to indicate an extension to the prehistoric workings.

7.6.1.2 Surface conditions

A small number of hammers carry organic residues, some of which are contained within the transverse modification groove. As they are all from museum collections, it is quite possible that some of the residues may be the remains of substances such as old label gum. One modified hammer is fire-cracked.

7.6.2 Description and analysis of end-worked hammers

7.6.2.1 Size

Unmodified hammers are, with one exception, less than 1.0kg in weight and would, therefore, have been hand-held. Modified hammers have a median weight of 1.45kg and demonstrate a similar size range to the Parys Mountain and Nantyreira material (fig. 7.27). Reused hammers have a median weight of 1.83kg (n=10). The smallest hammer is a miniature modified hammer, weighing less than 0.3kg, made from a fragment of a modified hammer.

7.6.2.2 Haft modification

Compared with the other assemblages, not only are a greater proportion of the hammers modified, but the form of modification is much more elaborate. Polish resulting from hafting is also much more developed which suggests that the hammers had a longer working life.

The work marks of modification consist predominantly of hard pounding with, on occasions, flaking at the margins of the stone. Striae have been recorded for two hammers, but in one case they may be post-depositional marks. In profile modification notches and grooves are superficial and concave, and only rarely U-shaped. Only one V-shaped profile has been recorded and this was for a lateral end groove (ALD.074; fig. 7.34C).

Groove-type haft modification in the transverse position is dominated by forms which encompass all or most of the stone (table 7.28, and fig. 7.30 to 7.35). Less extensive forms, edge and face grooves, are often used in combination with edge notching. The grooves are broad and deep over the edges of the stone, though not the faces. Notching of the edges seems to be less developed than grooving. Modification for multiple binding is rare. Only one example possesses multiple grooving in more than one position (ALD.057), giving a total hafting width of 70mm which encompasses 40 percent of the stone. The pounding of the edge on another specimen suggests that the binding was taken to either side of an edge projection to within two or three centimetres of the working end.

The position of the modification is frequently offset from the centre of the stone away from the worked end (fig. 7.33B) or towards the broader end, but not necessarily at its centre of gravity. This is most marked for hammers with lateral modification.

Lateral modification forms are narrower and shallower than transverse forms, and they show a lower degree of haft polish. Five out of the seventeen laterally modified hammers have been worked in such a way as to accept a multiple binding which includes the combined use of end and edge positioned modification. Only one laterally modified hammer has been used as a hammer at its modified end, although it is possible that its shallow patch of face pounding adjacent to the transverse groove is related to the transverse binding.

Laterally modified hammers are similar in roundness and axial shape to hammers with only transverse modification (table 7.29), but they differ in the degree of surface smoothness, weight and the number of edges/faces of the stone. This would suggest that lateral hafting was used for heavier stones and those less suited to hafting. They also appear to have been used to a slightly greater degree (table 7.23).

Some limited information about the hafting arrangement can be gleaned from a small number of hammers by studying the pattern of the polish made by the hafting. This polish tends to cover the full width of the transverse groove or notch and, in some instances, it extends beyond the groove over the natural face of the stone. Further measurements of the width of the haft binding are obtained from polish over fracture surfaces where the hammer has been rehafted. Ridges between facets of polish suggest that the transverse binding was arranged in both straight and twisted/plaited fashions which varied in width between 30 and 50mm (fig. 7.32). Polish resulting from lateral binding over the stones' faces is sufficiently well developed within the transverse groove of two hammers (ALD.039 & 042) to suggest that twisted bindings of about 10mm in width were used.

One of the modified hammers (ALD.047), which is dubiously attributed to Alderley Edge, is particularly unusual in form as it combines discontinuous edge pounding with modification grooving. The narrowness and superficial nature of the groove places further doubt on its attribution.

7.6.2.3 Use-wear

The use-wear marks of end-type working (table 7.33) reflect the working of soft sandstone and clay strata, as well as harder, pebbly and gangue-impregnated sandstone and mineral veins. Correlation analysis of the use-wear marks shows a positive correlation between polish striae and fracture flaking (table 7.30) which may, quite simply, reflect the working of soft pebbly strata. A division between soft/hard and heavier-duty hammers is also suggested but this is not borne out when making weight comparisons (fig. 7.29). Hammers possessing polish striae, on the other hand, are generally larger suggesting that smaller hammers were used to work harder rock.

7.7 General descriptions and comparisons

7.7.1 Edge-working of end-worked hammers

This type of working occurs most frequently for the Great Orme material (table 7.13). The Alderley Edge assemblage, in contrast, shows less extensive but more intensive working. In all the assemblages, this type of working is relatively undeveloped in form and comparable to secondary flake-edge working.

Most of the Great Orme material corresponds in size to the small, end-worked, hand-held hammers, which weigh less than 1.5kg, although they are more discoidal and have sharper margins.

7.7.2 Flake-edge working

For the main assemblages, around one-fifth of tool fragments and spalls have been employed as flake-edge tools. The working consists almost exclusively of pounding and flaking, although larger pieces have also been used for anvil working. The size and morphology of these tools are given in tables 7.31 & 7.32. Although a number of pieces in each assemblage show offsetting and faceted forms of working, mostly indenting and dual-faceting, the working is relatively undeveloped. None of these tools showed evidence of hafting. It would appear that these tools were not used directly in ore extraction. The exception is one piece from Great Orme which exhibits signs of very soft pounding.

7.7.3 Striae use-wear marks

Striae and scratches are relatively rare (table 7.33). They are mostly associated with anvil working and rarely occur in isolation. In a small number of cases they may be related to haft modification. They are usually short and broad, generally between 4 and 11mm in length and 1 and 3mm in width, and few in number. As a result of glancing blows, they are most well-developed at the margins of the working area. Regular directions of working, such as grid and parallel patterning are rare. In the example illustrated in figure 7.26, the working on the face is offset to one end. In conclusion, it would seem likely that these marks are the result of hammering such tools as metal chisels or gads.

7.7.4 Worked stone and stone tools unrelated to ore extraction

A small number of tools exhibit use-wear forms that would not have been produced through ore extraction and dressing (table 7.33). These may form separate tool types or occur in combination with use as mining tools. A number of the tools may be indirectly related to mining activity, i.e. pecking hammers for haft modification and the whetstone for sharpening metal mining tools. The most unusual forms are found at Great Orme and these are described in detail below. In addition, worked stone discs have been recovered and these are also described separately below.

7.7.4.1 Specialist tools from the Great Orme

GOR.226 - anvil and hammer (fig. 7.16). This is a large, tabular, end-worked hammer which has an unusual form of use-wear on both faces. This consists of random scratches and striae which are short (around 3mm in length) and very fine. The flatter face contains three smooth circular patches, two of which are slightly hollowed. One explanation could be that the stone was used as a block for shaping something to a point. This would include making wood chips or splinters, for example, for use as torches or in starting fires. No parallels to this tool have yet been found.

GOR.247 - pounder (fig. 7.13C). This is a small, discoidal, pounder used to crush and grind a hard substance against a flat surface. Its edge has been pounded into smooth, broad, flat facets while both its faces contain double dimples of pounding.

GOR.334 - pounder and anvil. This is a small, ovoidal, cobble whose ends are polished and very softly pounded. Both faces contain three equally spaced, small, circular pounded, hollows aligned in a diagonal to the long axis of the stone. On both sides, the middle hollow, which is located at the centre of each face, is smaller, deeper and more heavily pounded than the other hollows. A collection of similar stones is held by St. Helens Museum and Art Gallery, but, unfortunately, few details are known about these finds.[2]

7.7.4.2 Stone discs

Five shale discs have been recovered during the recent excavations at Copa Hill (fig. 7.19 to 7.21). Four of these were found within the surface horizon of trench D2, which was located at the mouth of the opencast. The fifth, a smaller and more finely shaped example, was found on the tip surface. They are roughly oval to circular discs, weighing from 0.54 to 1.26 kg and measuring from 100 to 171mm in diameter. They consist of soft, subrounded, stones with rough surfaces, which are characterized by heavy, offset edge pounding and flaking. As this working is fairly continuous around the edge and lacks facets or patches of softer working through more concentrated use, it is thought to represent crude shaping rather than use-wear.

A shale disc, described as a 'lid', was also found at surface on Parys Mountain by Davies (1939). It is smaller and more regularly shaped than the Copa Hill examples. Davies found another specimen in what appeared to be modern contexts from within the mine of

Newton Park near to Newtown (Davies 1938). The near-surface contexts of all these finds may suggest that they are of recent date.

7.8 Comparison of the results with the Mount Gabriel study

The Mount Gabriel material (O'Brien 1994, 117-135) is comparable in size to that of Parys Mountain and Alderley Edge (fig. 7.36), but smaller than the Copa Hill assemblage. This may be explained by the form of the mine workings as the Mount Gabriel mines, consisting of inclined tunnels up to 11m in depth and several metres in section, would be similar in form to the pit-like workings reported for Parys Mountain and Alderley Edge.

A higher proportion of the Mount Gabriel hammers are modified than the Welsh material, and a greater proportion were discarded in the serviceable state. Although a small number of unused cobbles were recovered akin to the Welsh sites, none of these are reported to have been modified. For comparative purposes, the material studied for this thesis has been classified as prematurely fractured where it displays only a trace amount of use. The proportion of prematurely fractured hammers is, in general, low and related to the hardness of the mineral deposit. The Mount Gabriel material shows a lower degree of breakage but a higher degree of premature fracture than the Welsh mine sites with hard mineral deposits. In addition, a higher proportion of the Mount Gabriel hammers are worked on one end only than the other assemblages. Whether this is related to the method of modification or differences in tool consumption is unknown. O'Brien's (1994, 127) observation that more extensive haft modification is associated with greater cobble sphericity supports the findings made for the Great Orme and Copa Hill assemblages that modification was required for more rounded cobbles. The Great Orme and Alderley Edge hammers exhibit comparable sphericity to the Mount Gabriel assemblage (fig. 7.36). The Copa Hill, Parys Mountain and Nantyreira material is too damaged and broken for comparison.

7.9 Summary and general remarks

The form and type of extractive tooling divides the assemblages into two groups: Copa Hill, Parys Mountain and Nantyreira where the mineralization is contained within hard host rocks, and Great Orme and Alderley Edge which are soft ore deposits. Mining tools used to work the harder vein mineralization display a higher degree of use as well as damage and breakage (tables 7.34). They lack the functional specialization, however, both in the form of size/use-wear groups and in the separate tool-type classes, shown by the other two assemblages. Instead, they show a higher rate of both recycled and joint usage. Furthermore, edge-working is more extensive for reused tools than for the primary ones - the reverse pattern to the sites with soft ore deposits. This greater pressure on use is also reflected in the evidence for increased care in the selection of suitable cobbles (table 7.2 & 7.35) and the low number, or lack of, unutilized cobbles.

The time and effort of obtaining suitable cobbles for use as tools would have been fairly great for all the sites. Even in the cases of Alderley Edge and Nantyreira where the stream bed sources are more accessible to the mine sites, the collection of cobbles would still have been time consuming due to their low stone content and the generally lower suitability of the stones. The distance and height gain required to bring in cobbles does not appear to be directly related to the consumption of stone tools since a sizeable part of the Great Orme assemblage was discarded in a still serviceable state. This is despite the fact that the mine is located 150m above, and almost one kilometre away from, the sea. The mine spoil has been observed to yield proportionally fewer stone hammers than other sites (Lewis 1994) but this may be explained by the softer nature of the ore deposits which demanded different tool materials as attested by the profusion of preserved bone remains.

For the Great Orme several types of unmodified end-worked hammers have been identified. Small hammers with very soft pounding marks are thought to be the result of hammering bone points into thin soft shale beds at the sides of the mine workings in order to extract ore. The extent to which bone tools have been used in this way, however, has yet to be studied. Small hammers showing evidence of soft/hard pounding, the most common form of hammer, would have been most suitable for working ore contained within vugs. The larger hammers exhibiting hard pounding and heavier forms of working, are common in size to the other assemblages, weighing roughly between 1.0 and 7.0kg. Both unmodified and modified end-worked hammers and edge-worked hammers have a similar size range. The comparison of working forms which have resulted from the use of the hammer at an angle to its long axis (table 7.11) demonstrates that unmodified and modified hammers were used in the same way. These forms would suggest that hafted hammers were also used as hand held tools. It is only for the Copa Hill assemblage that a greater degree of use is implied for modified hammers. There is also evidence to support the theory that the size of the Alderley Edge modified hammers is related to the hardness of the sandstone strata being worked.

The Great Orme assemblage is the only one to have both edge-worked and end-worked hammers weighing over 7kg. The two largest hammers, weighing at least 29kg, were both found in a large underground stope, thought to be prehistoric. It is suggested that these were cradled and swung against the mine face. Judging by the relative abundance of large hammers, they could have been used extensively in trench and stope working. The absence of similar sized hammers, associated with the large openwork at Copa Hill, would imply that they are only effective in working relatively soft mineral-bearing rock.

The proportion and form of haft modification appears to be related to the physical properties of the stone tools, as well as to the hardness of the ore deposit. All four Welsh assemblages show a similar pattern of modification (tables 7.36 to 7.38), i.e. relatively undeveloped working and short-lived use. The Alderley Edge material, which shows much greater development and elaboration, consists of a higher proportion of weathered rocks and softer rock types meant that they were more easily worked. The higher degree of haft polish combined with the higher degree of damage but relatively low rate of breakage, demonstrates that these hammers had a long life which made modification on this scale worthwhile.

The presence of well developed mortars and numerous pounders and cobbing hammers for the Great Orme assemblage suggests that they date to later exploitation of the harder chalcopyrite ore. Some of these mortars have also been used as minor end/edge hammers. There is also evidence to suggest that mortars from Cwmystwyth, unassociated with prehistoric mining, have been used in this way too. In addition, for Great Orme there is some limited evidence to suggest that the mortars are contemporary with extractive stone tooling and circumstantial evidence to support the theory that metal tooling was also being employed during this later period of exploitation. This was in the form of hammerstones, bearing striae use-marks and found at depth in the mines. For the other Welsh sites, the small number of stone tools with striae marks, most usually in the form of anvil-type working, may also be related to metal tooling. Furthermore, it is possible that notched end-working also reflects metal tooling.

For both the Great Orme and Alderley Edge sites, a small number of the cobble tools have been derived from more local sediment sources than the bulk of the assemblage. In both cases the stones have a distinctive set of physical properties which has limited their use to particular tool classes. Again, this can be attributed to the fact that there was lower pressure on use than for the other assemblages.

Worked stones in the form of shale discs have been recovered from Copa Hill and Parys Mountain. The smaller and more finely worked examples, i.e. the single find from Parys Mountain and one of the Copa Hill specimens, may have been lids to ceramic vessels. It could be suggested that the crude discs are lids to crucibles but no such association has yet been made.

A small number of tools show use-wear forms which may be indirectly related to mining. This includes stone dressing forms which could point to the modification of cobbles for hafting. For Great Orme, the presence of a small number of more specialized tools may be suggestive of small scale metalworking activity.

Notes

[1] A further 'grooved' hammer is on display in the Visitors Centre.

[2] Accession numbers 1932/10/1.1 & 1.2, 1945/1/1 and 1945/1/1, plus two unaccessioned items donated by Dr. S.B. Siddall.

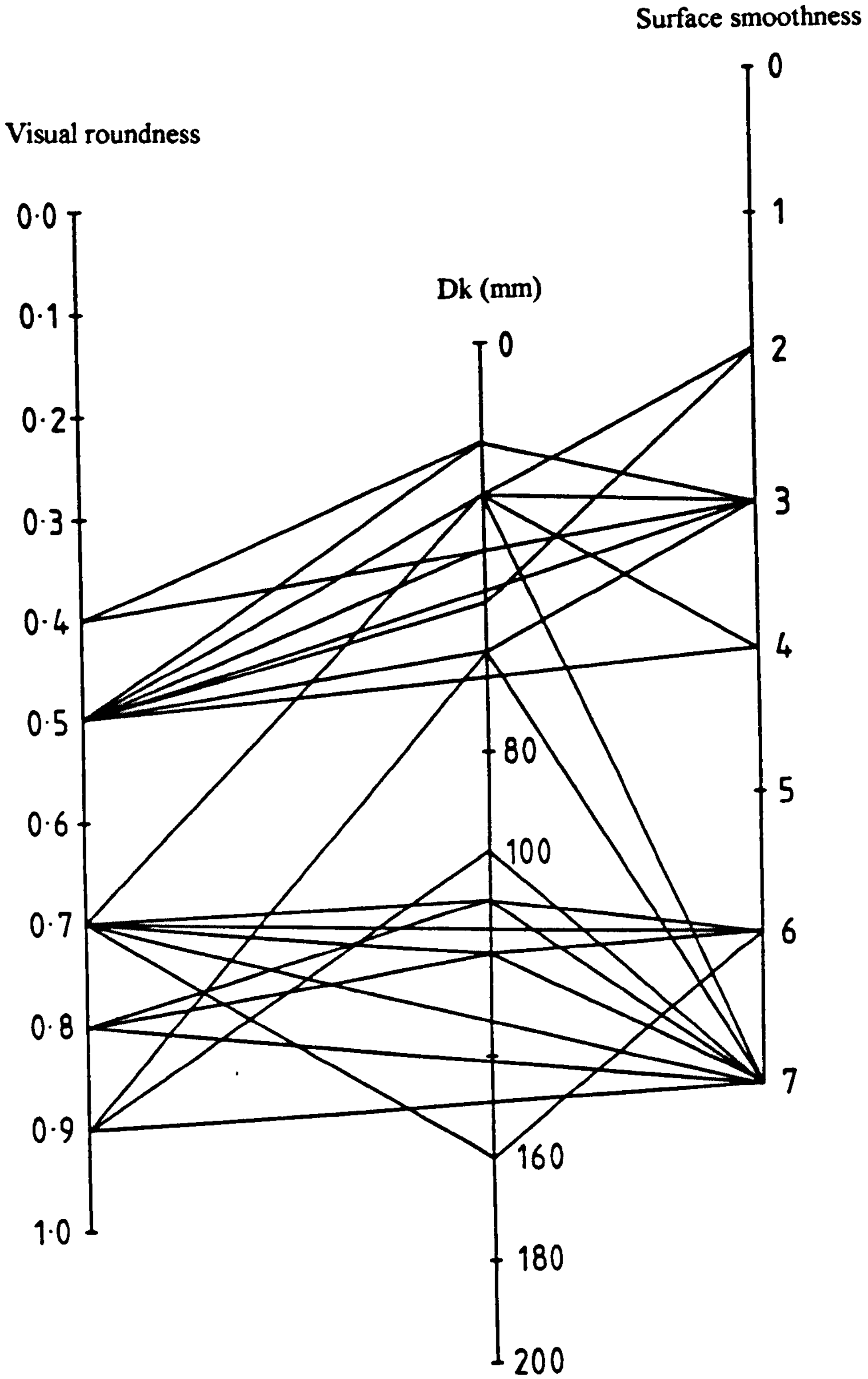


Figure 7.1 A three-dimensional graph of limestone cobble morphology, the Great Orme assemblage. This is a vertical plot in three axes for the variables visual roundness, the diameter of the sharpest corner and surface smoothness. There are sixteen limestone tools which separate into two types: angular to subangular rock fragments and rounded to well-rounded cobbles.

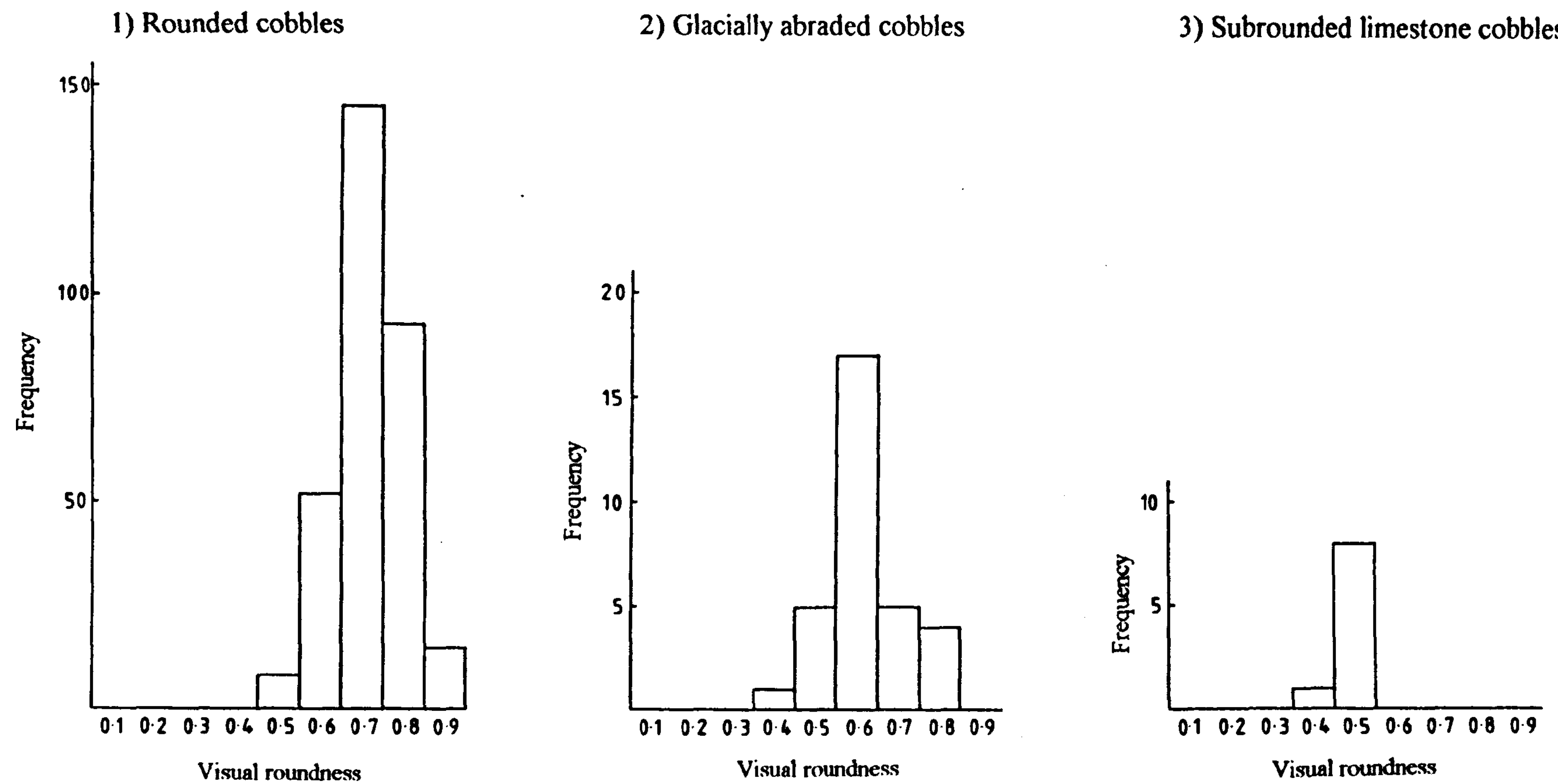


Figure 7.2 Visual roundness histograms for cobble types, the Great Orme assemblage.

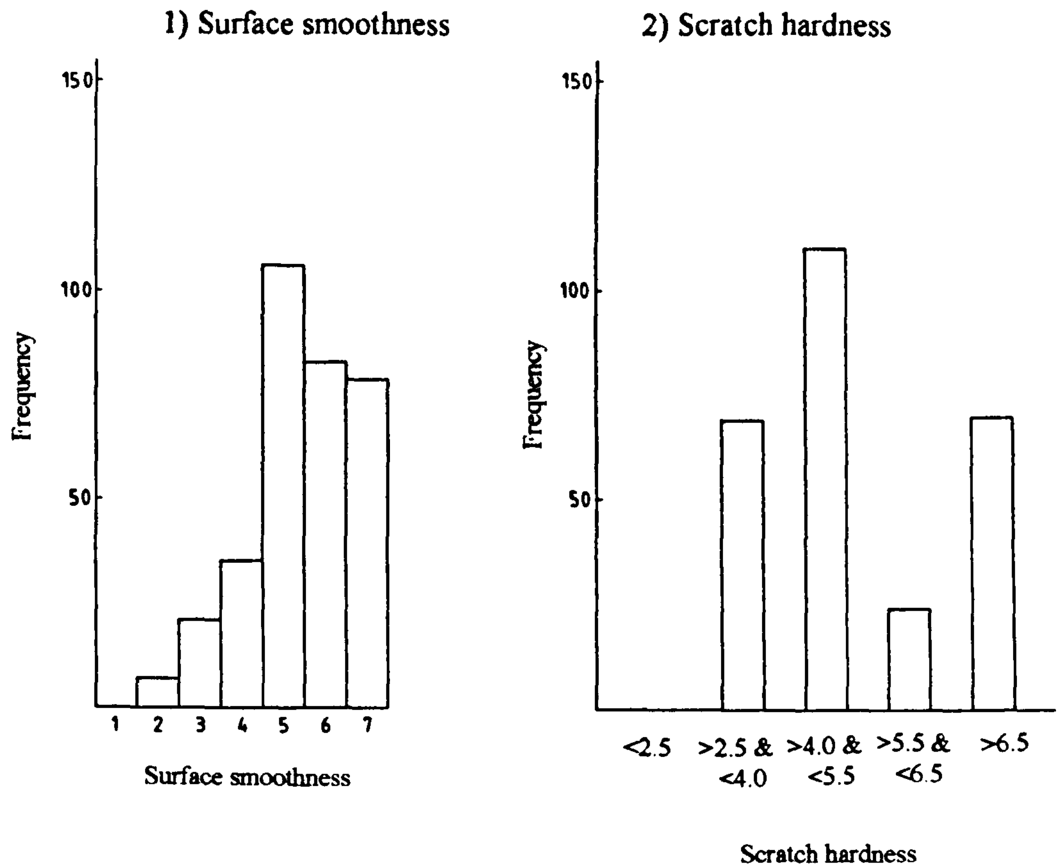


Figure 7.3 Histograms of physical properties for the Great Orme assemblage.

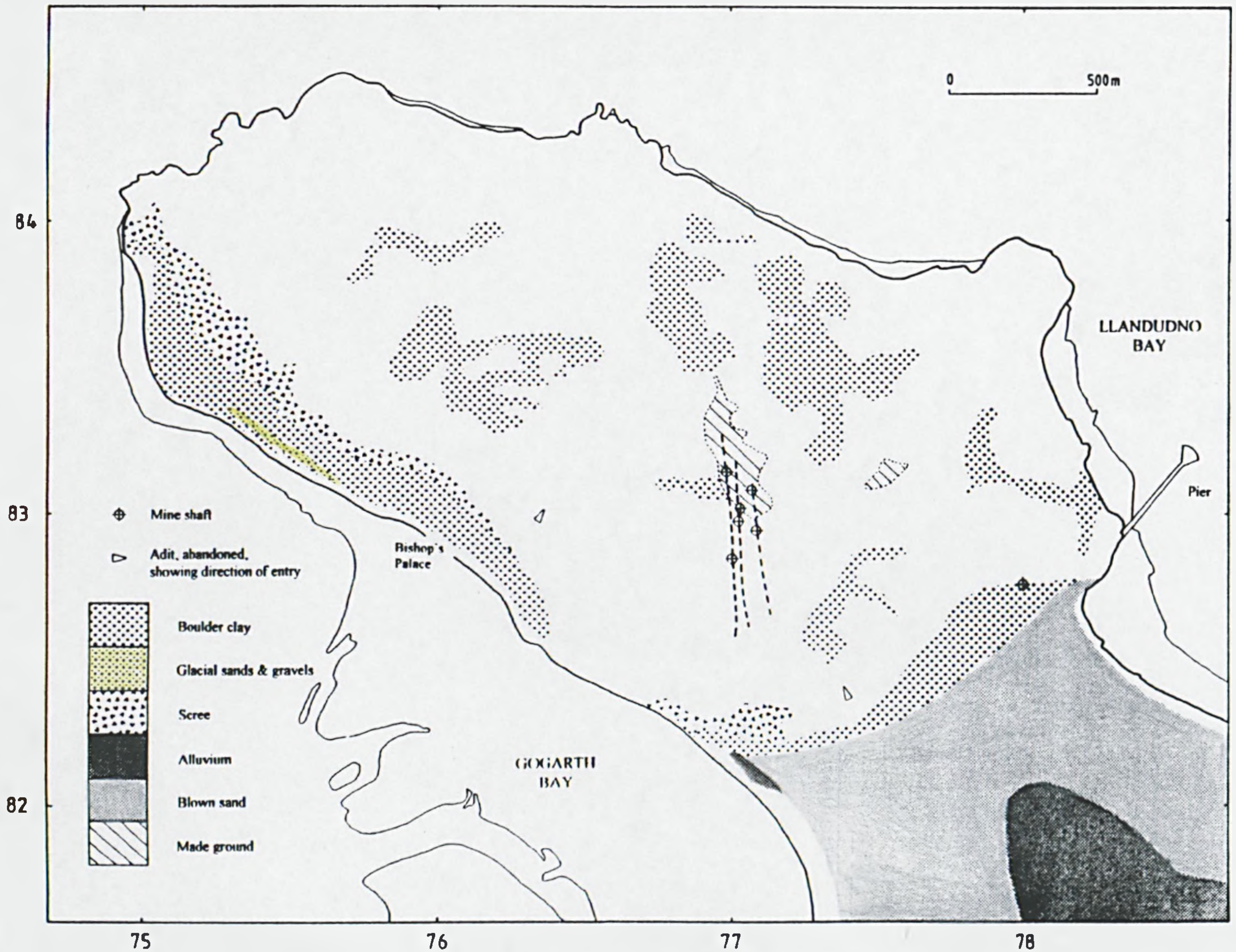
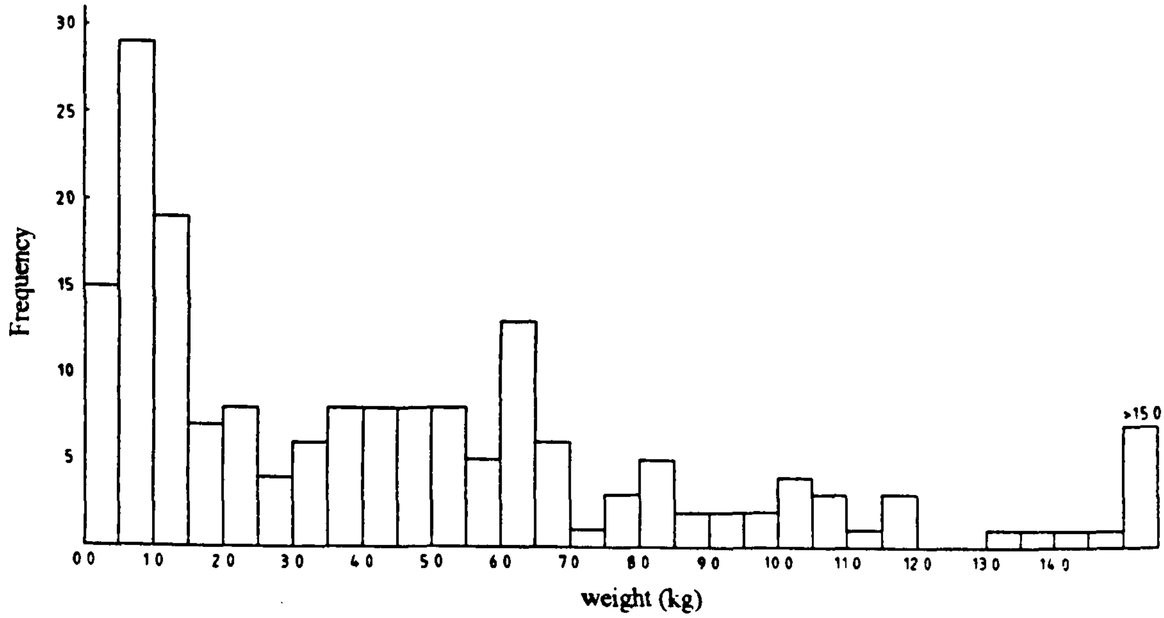
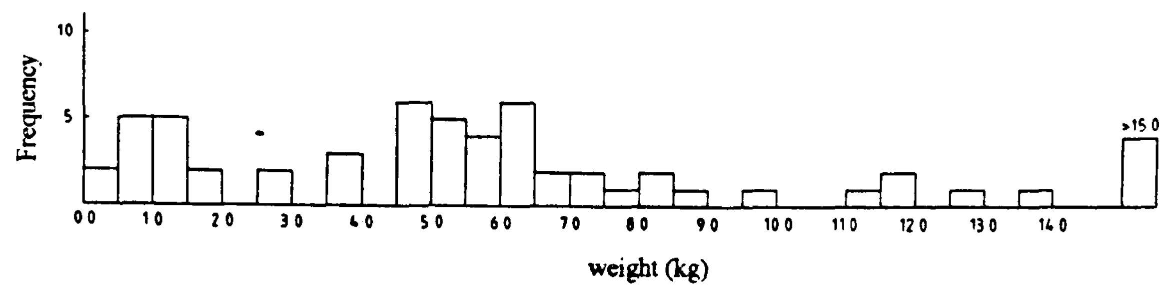


Figure 7.4 The geology (drift) of the Great Ormes Head (transcription of the BGS 1:10 000 series dyeline map, 1988, sheet SH 78 SE).

1) Unmodified end-worked hammers



2) Damaged unmodified end-worked hammers



3) Unutilized cobbles

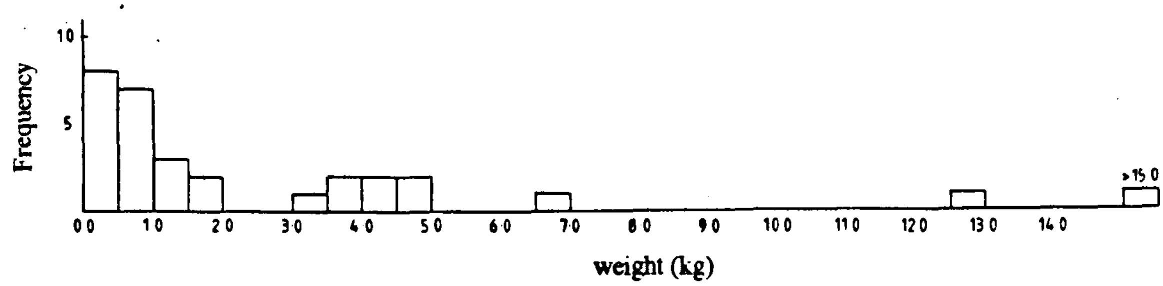


Figure 7.5 Histograms for stone tool and cobble weights for the Great Orme assemblage.

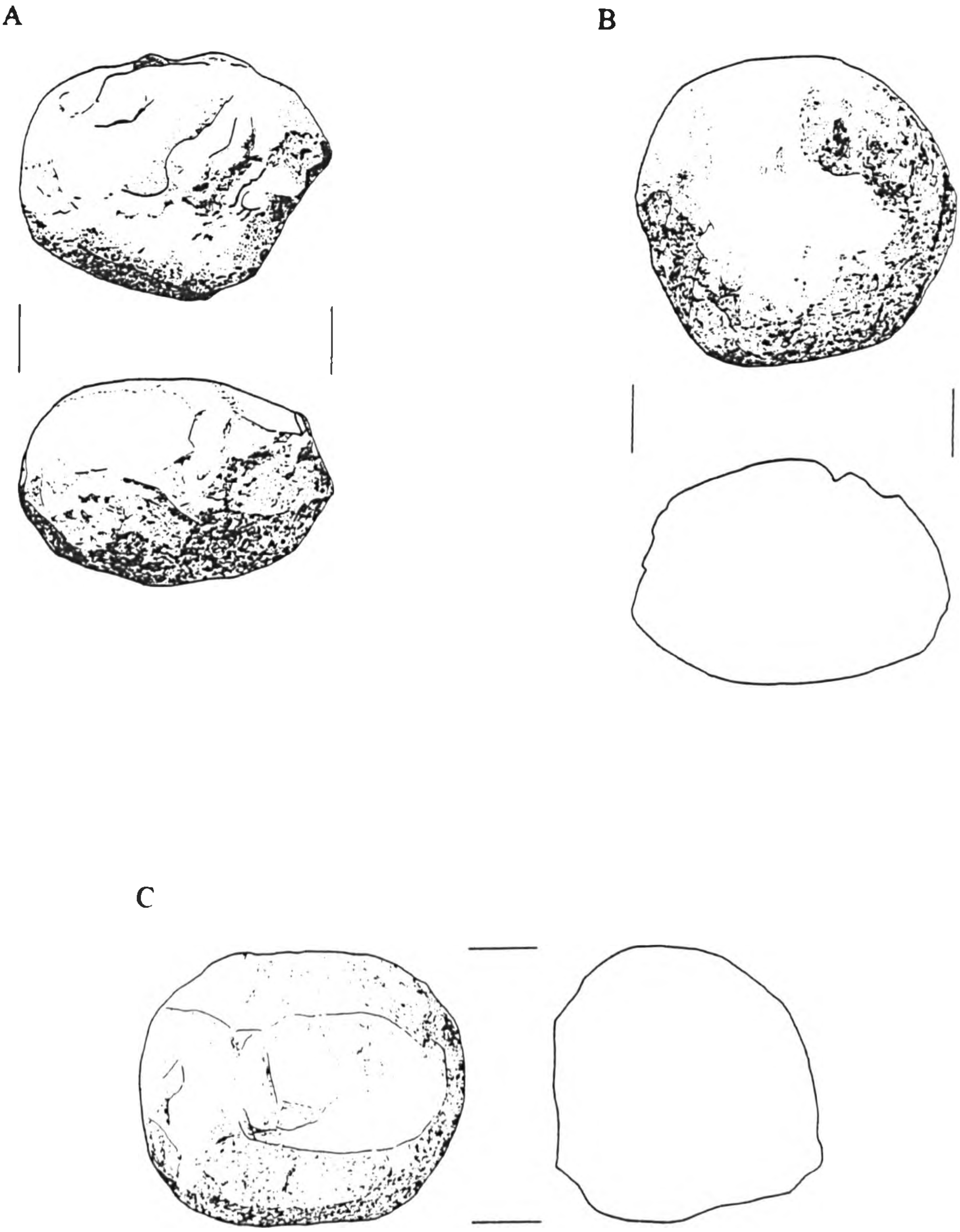


Figure 7.6 Limestone tools, the Great Orme assemblage. A - GOR.239, pounder; B - GOR.119, pounder; C - GOR.126, rounded pounder. Scale 1:2.

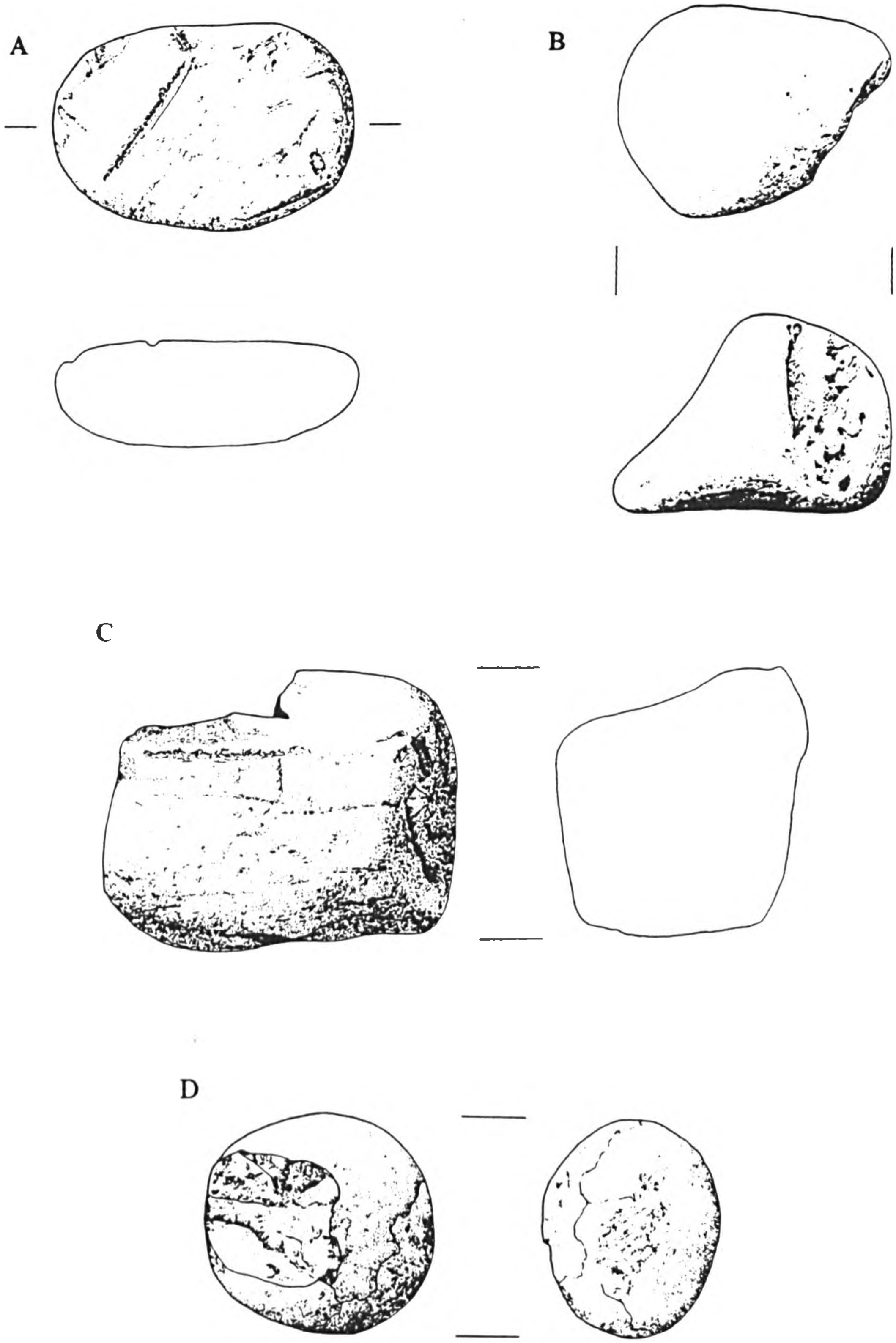
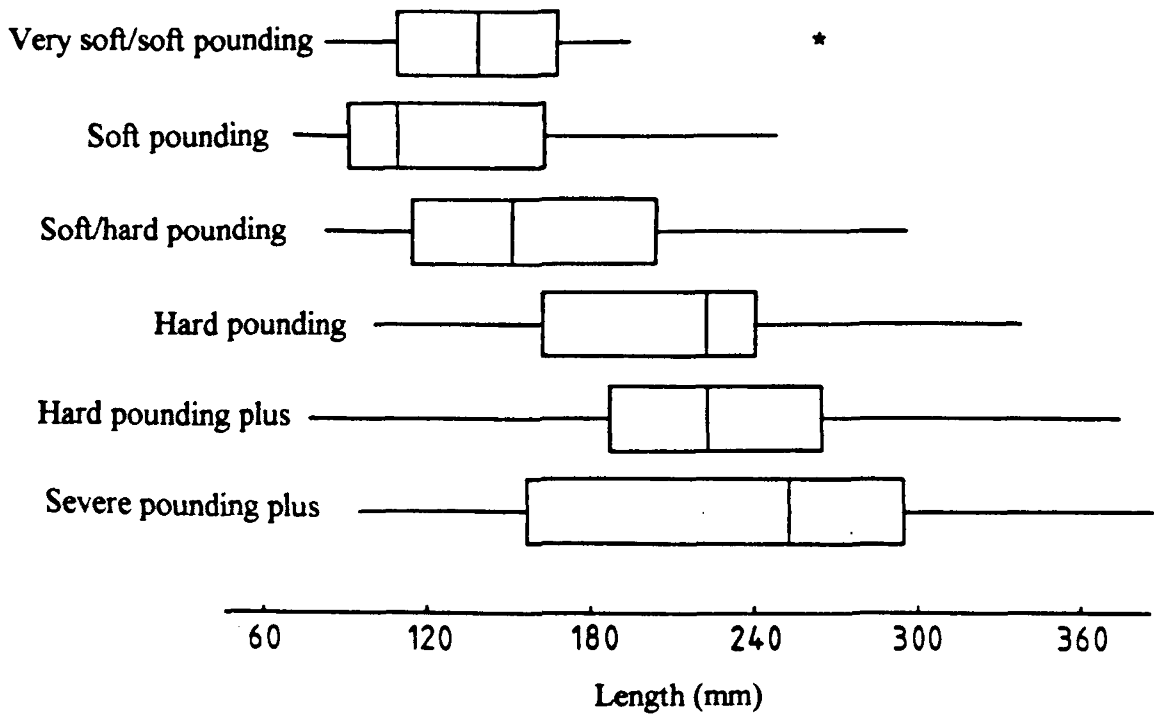


Figure 7.7 Small cobble and hammers from the Great Orme assemblage. A - GOR.361, unused cobble (note the broad glacial striae); B - GOR.210, hammer (glacial faceting and snub scar); C - GOR.359, hammer (glacial faceting and well defined plate scar); D - GOR.351 - fire-cracked hammer. Scale 1:2.



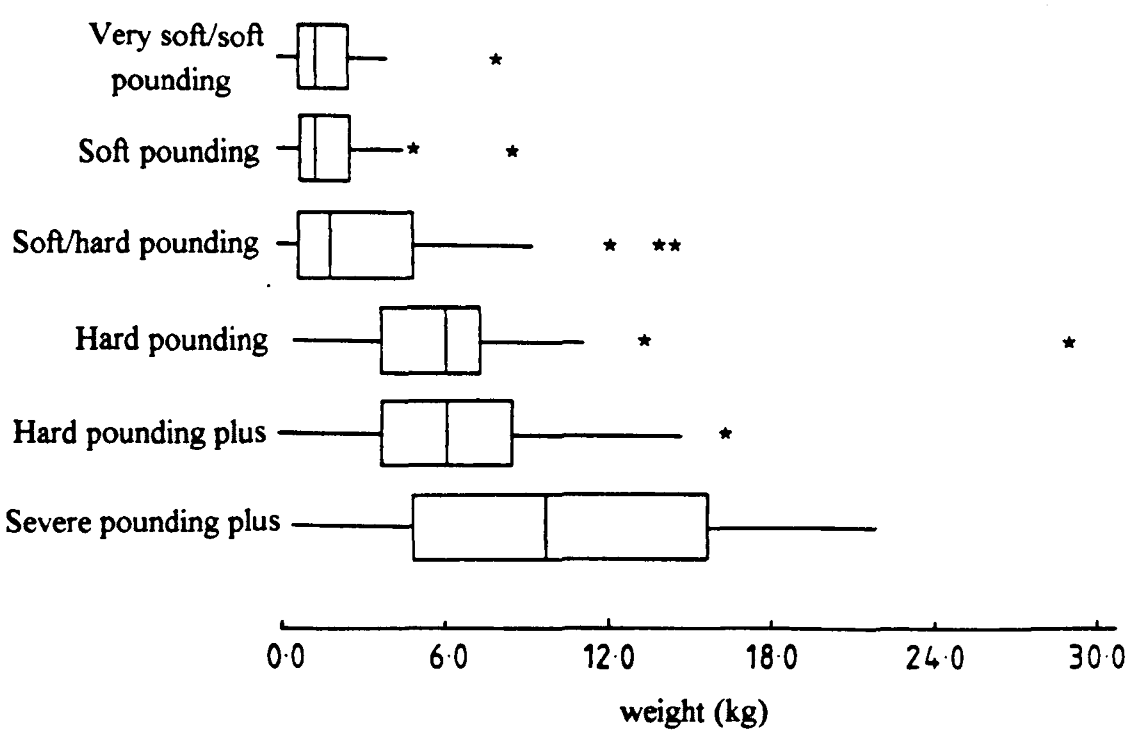


Figure 7.8 Box plots of the size of end-worked hammers, according to use-wear types, for the Great Orme assemblage.

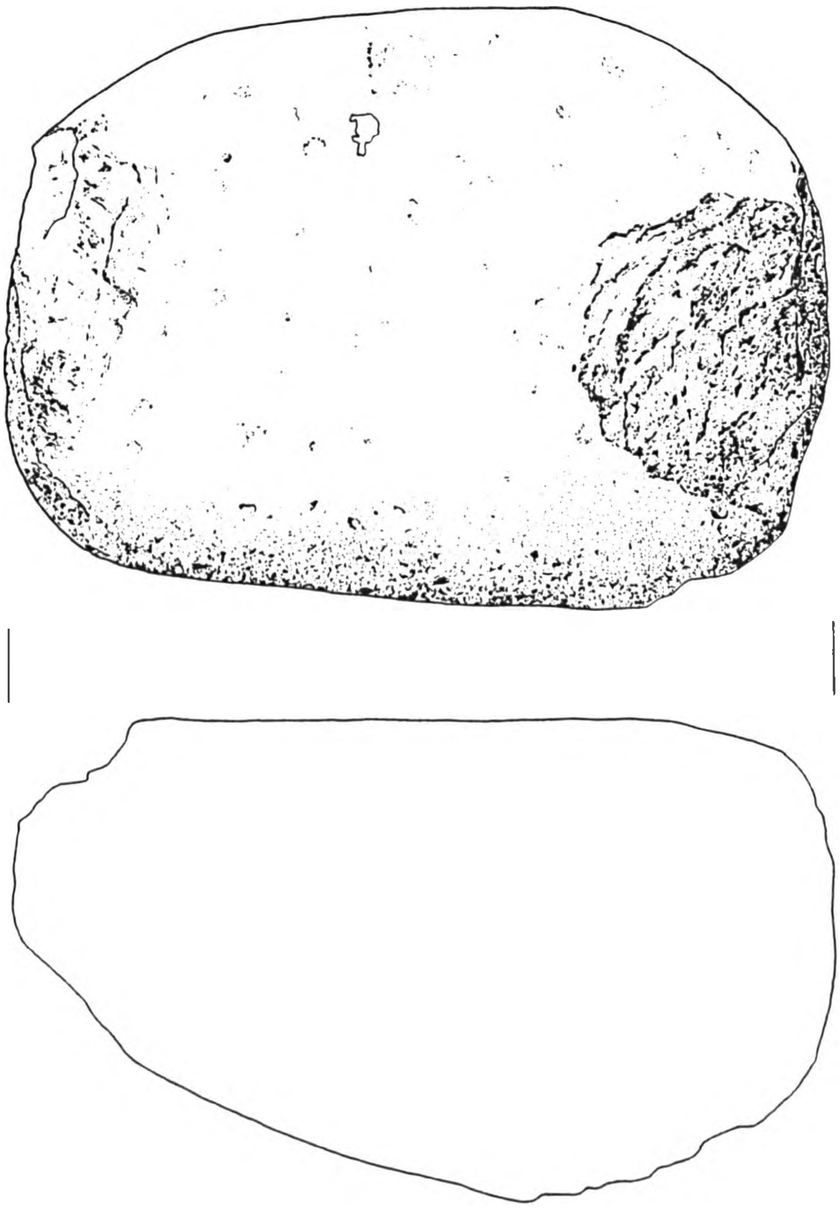


Figure 7.9 Large hammer from the Great Orme Mines (GOR.287) displaying heavy use-wear. Scale 1:2.

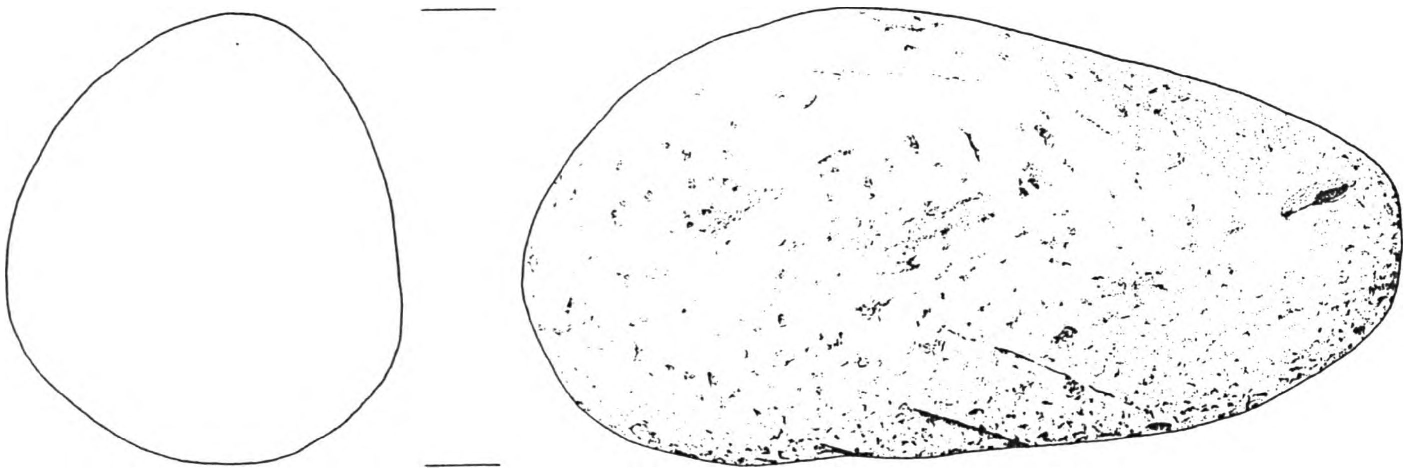


Figure 7.10 Large hammer from the Great Orme Mines (GOR.080) with a highly smoothed surface and well developed pitting and plate scars typical of a pyroclastic beach cobble. Scale 1:2.

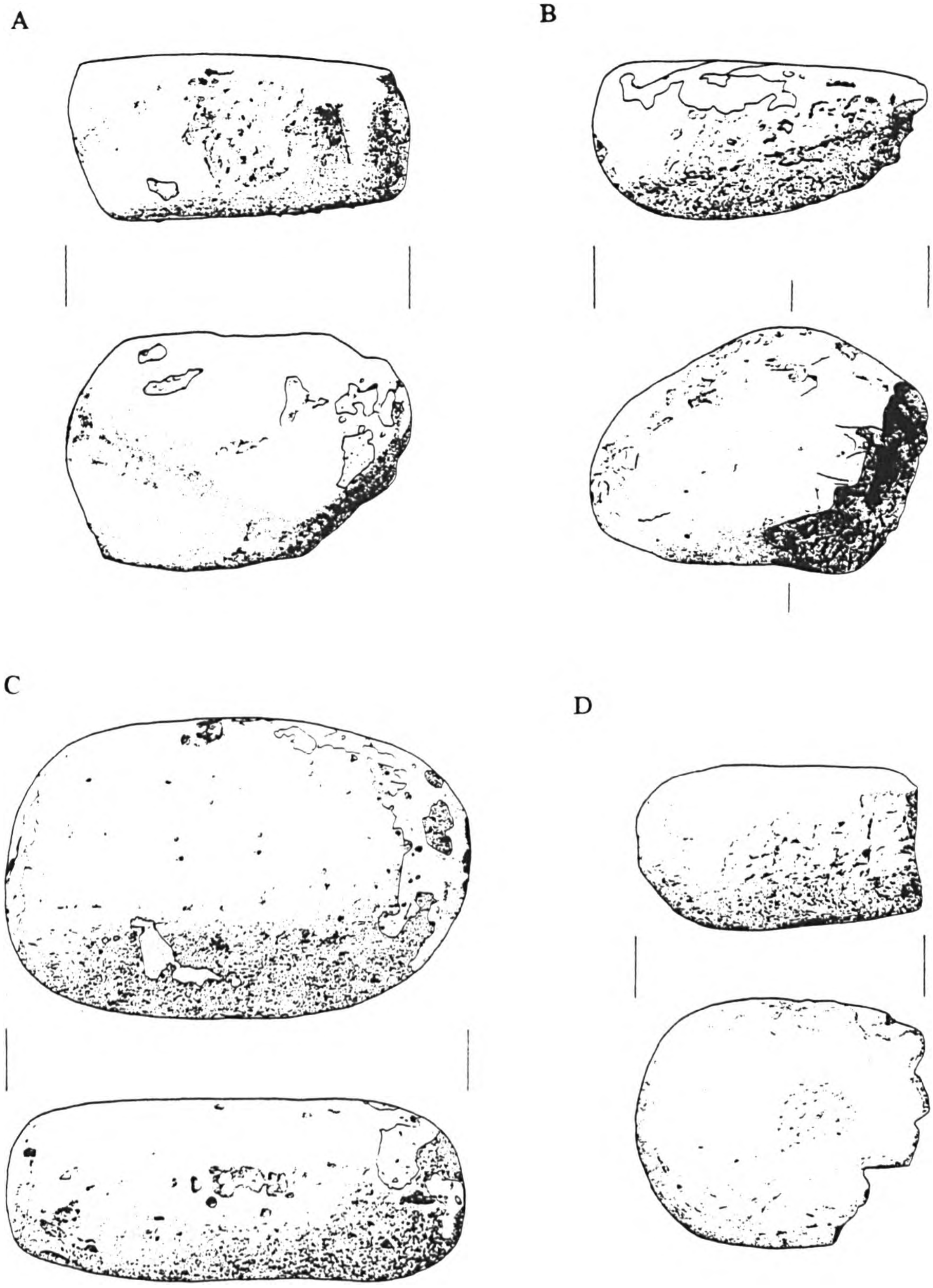


Figure 7.11 Modified hammers from the Great Orme Mines: A - GOR.211, modified by surface abrasion on one edge; B - GOR.355, edge abraded either side of edge projection; C - GOR.224, abraded on both edges (note the flowstone coating); D - GOR.104, fire-shattered with patches of pounding on both faces as well as both edges. Scale 1:2.

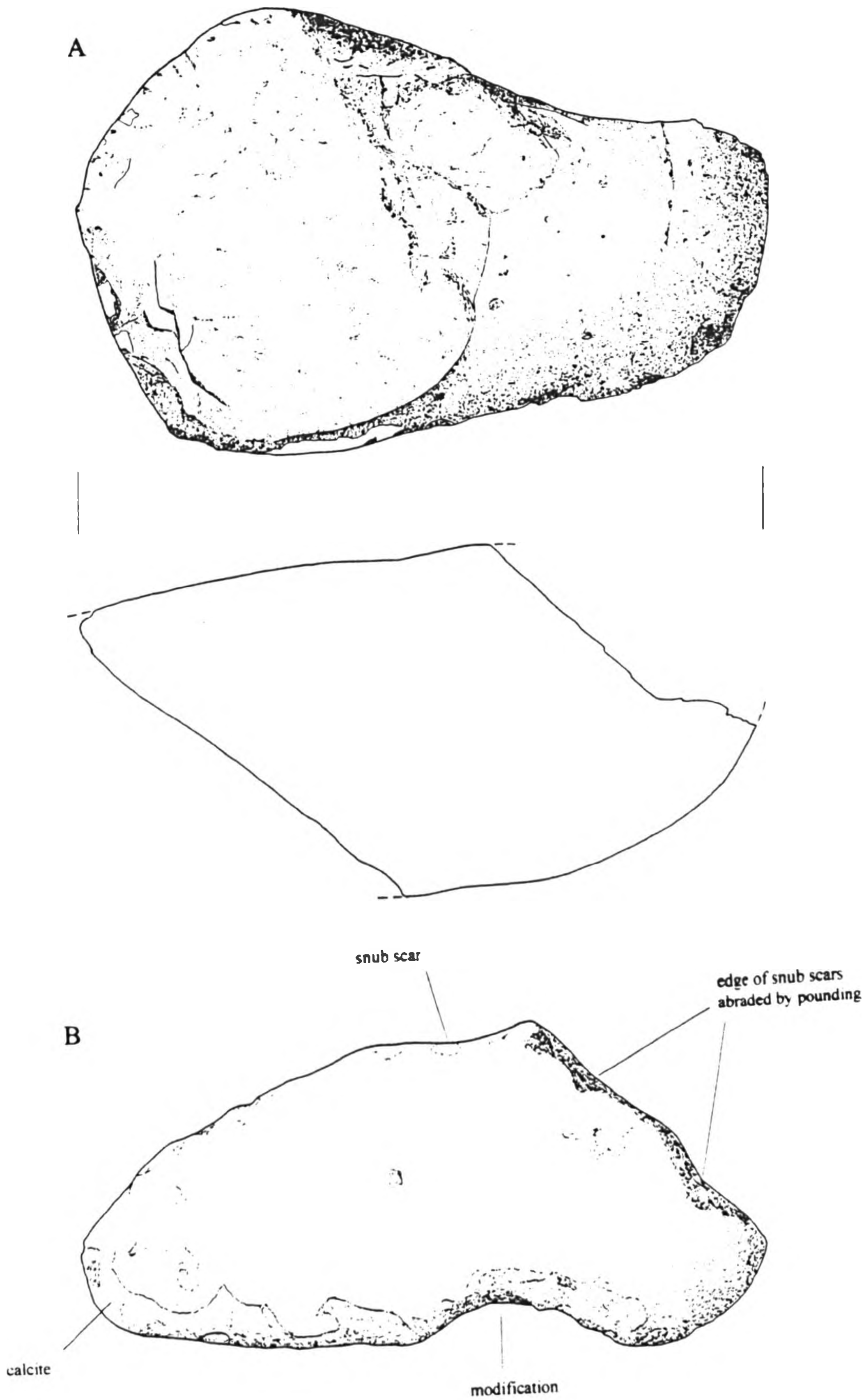


Figure 7.12 Modified hammers from the Great Orme Mines: A - GOR 348, upper edge modified by a notch; B - GOR 159, snub scars exploited for hafting and modification. Scale 1:2.

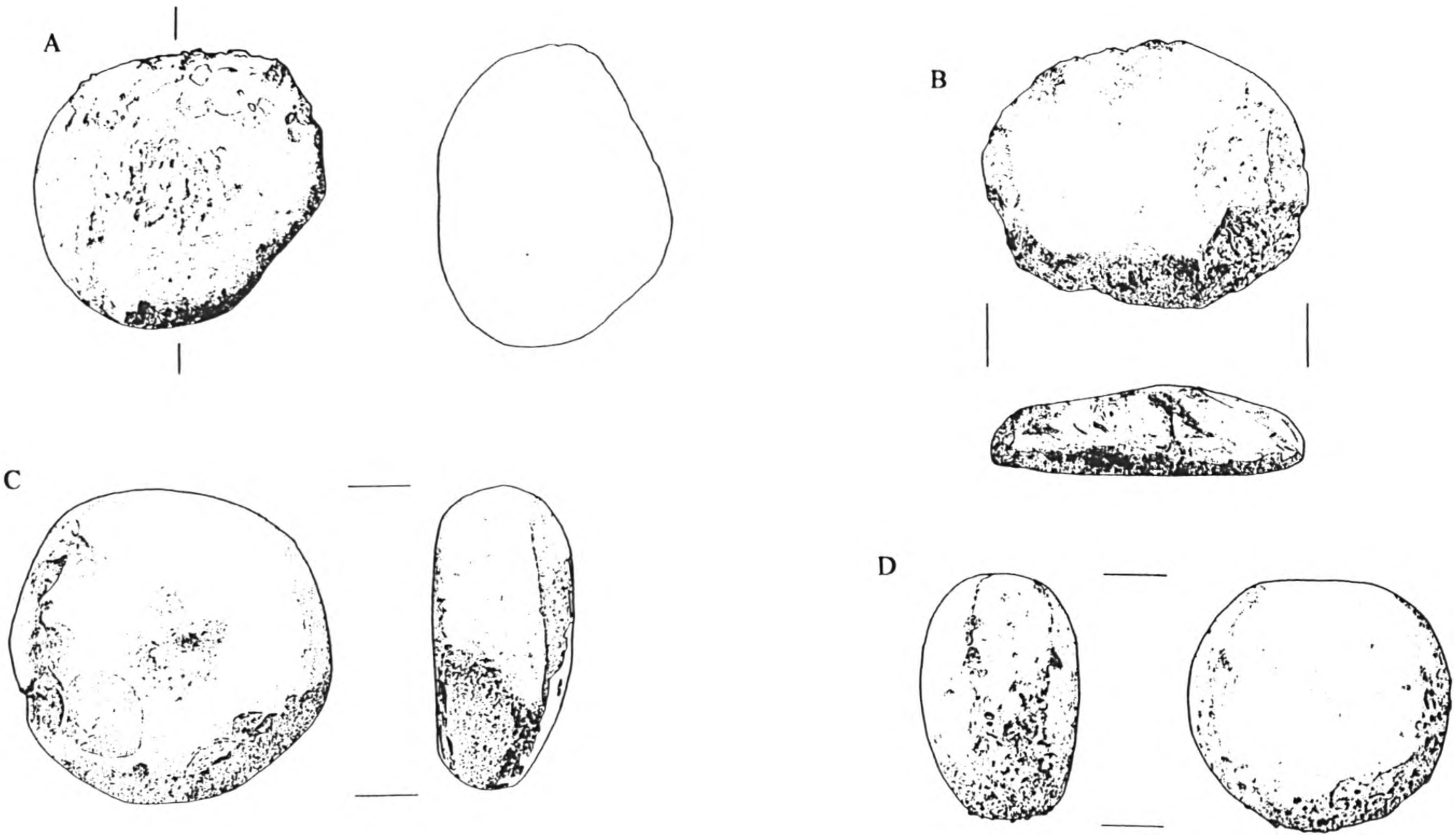


Figure 7.13 Edge worked pounders and hammers from the Great Orme Mines: A - GOR.059, hammer fragment reused as a cobbing hammer; B - GOR.231, offset edge-worked hammer; C - GOR.247, specialized pounder with faceted edge pounding and pounded dimples on both faces; D - GOR.246, pounder with ridge-faceting. Scale 1:2.

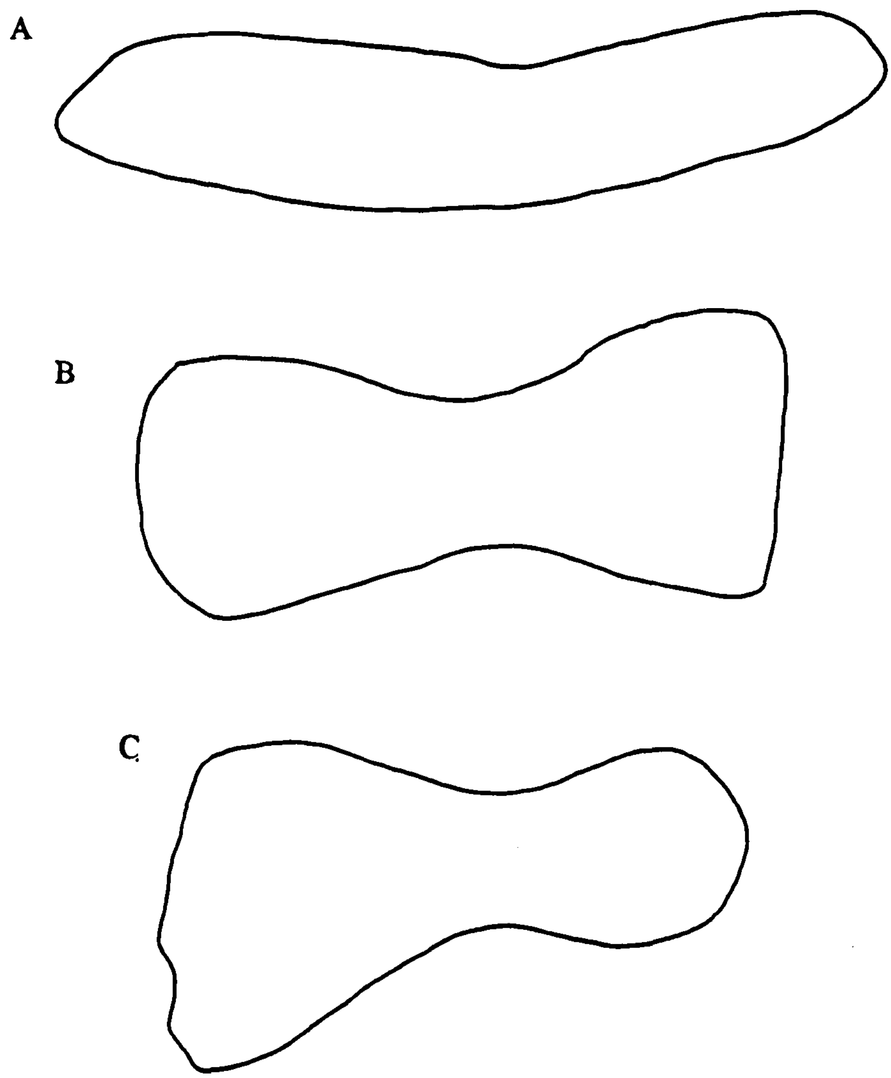


Figure 7.14 Mortars in cross-section from the Great Orme Mines. A - GOR.111, compound form of working; B - GOR. 112, compound working on both faces; C - GOR.110, edge damaged from hammering. Scale 1:3.

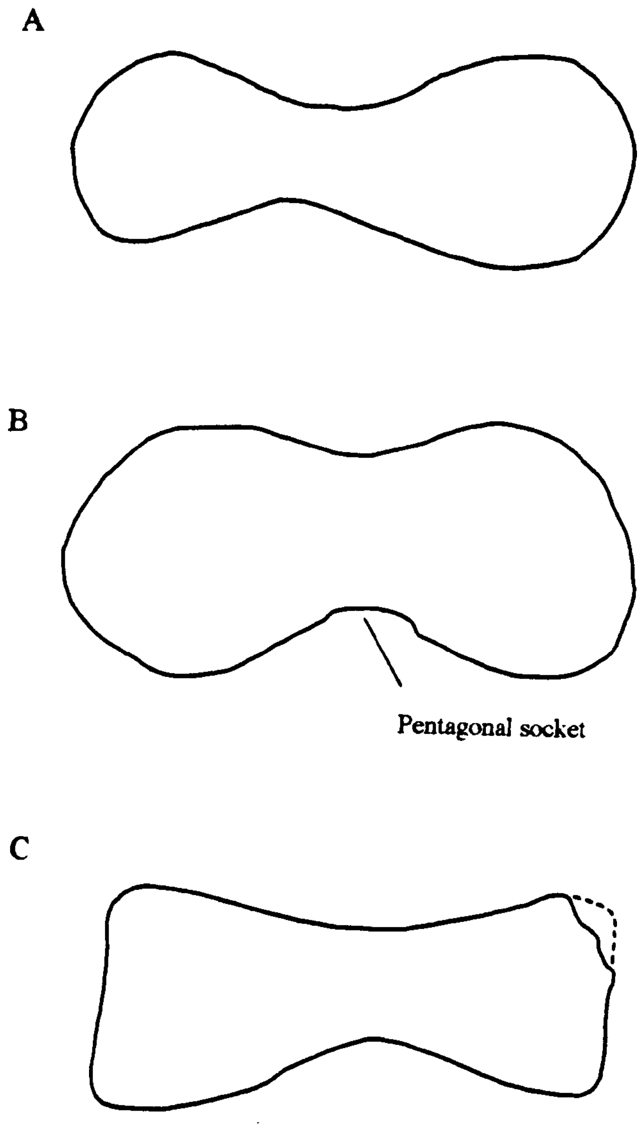


Figure 7.15 Mortars in cross-section. From the Great Orme Mines: A - unnumbered; B - GOR.335, centre of lower face containing later (?) socket. From Graig Fawr, Cwmystwyth, C - COP.217, with damaged end from hammer working. Scale 1:3.

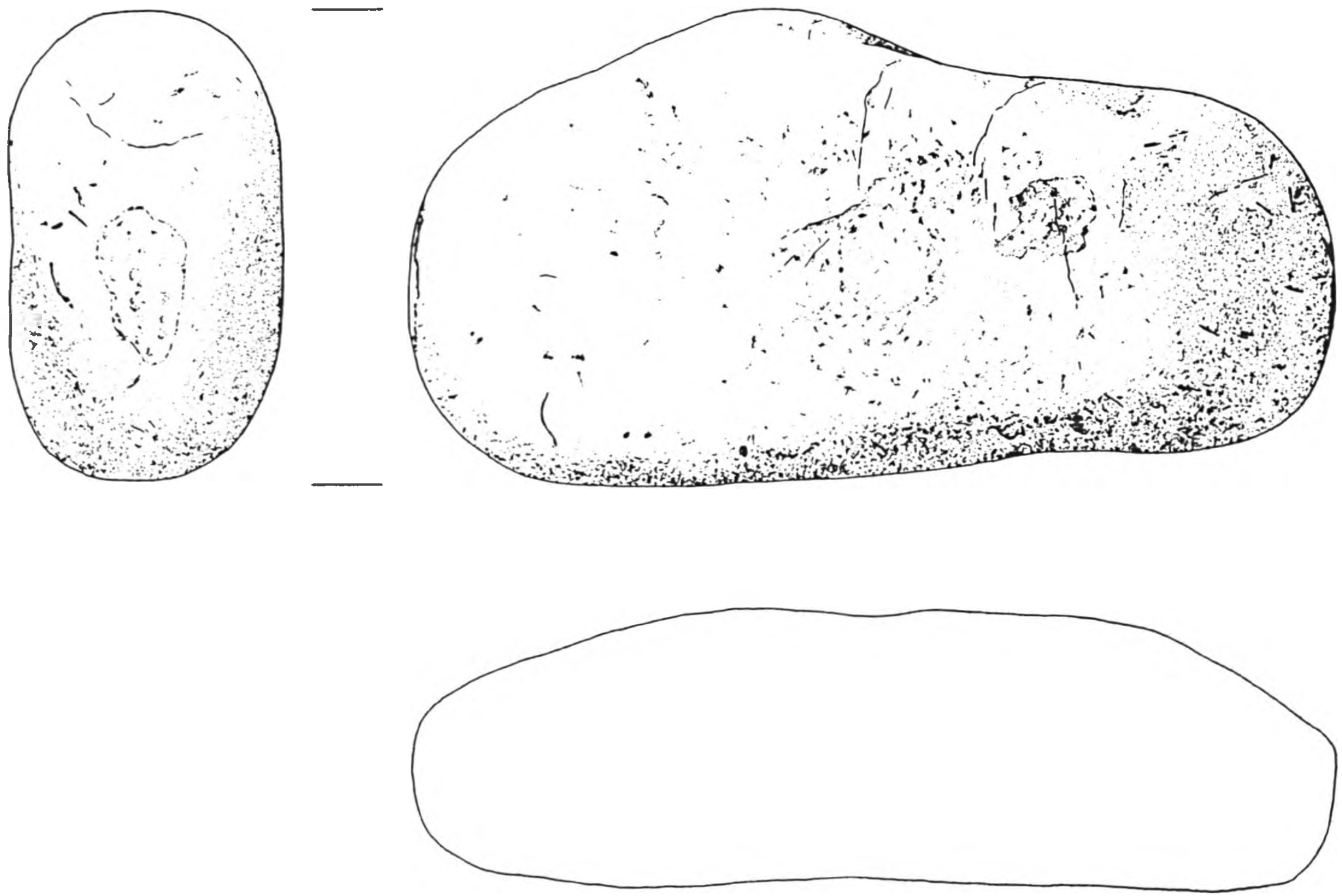


Figure 7.16 Hammer (GOR.226) with specialized anvil working from the Great Orme Mines. Scale 1:2.

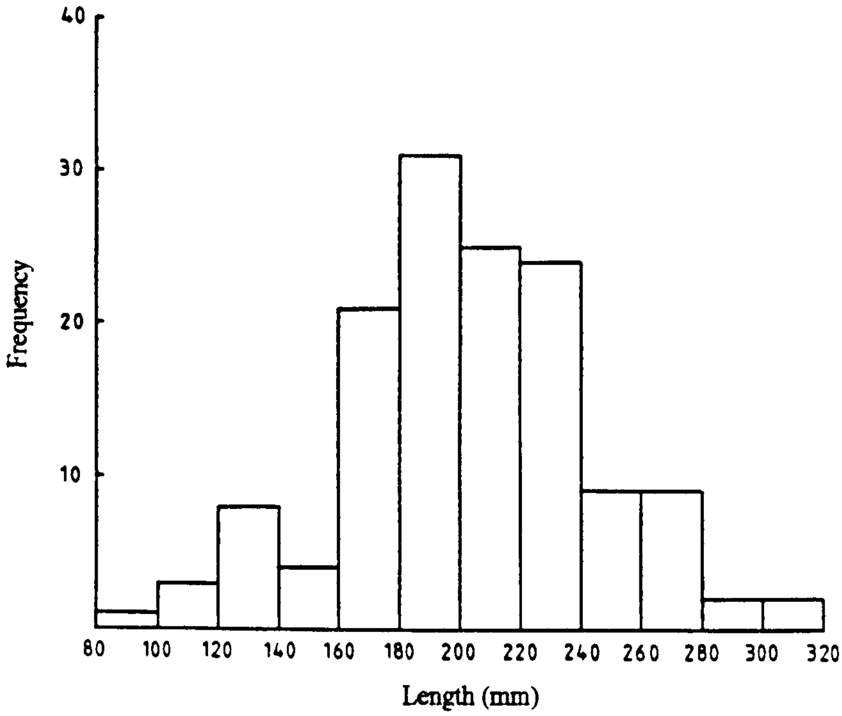


Figure 7.17 Histogram of damaged lengths for the Copa Hill hammers.

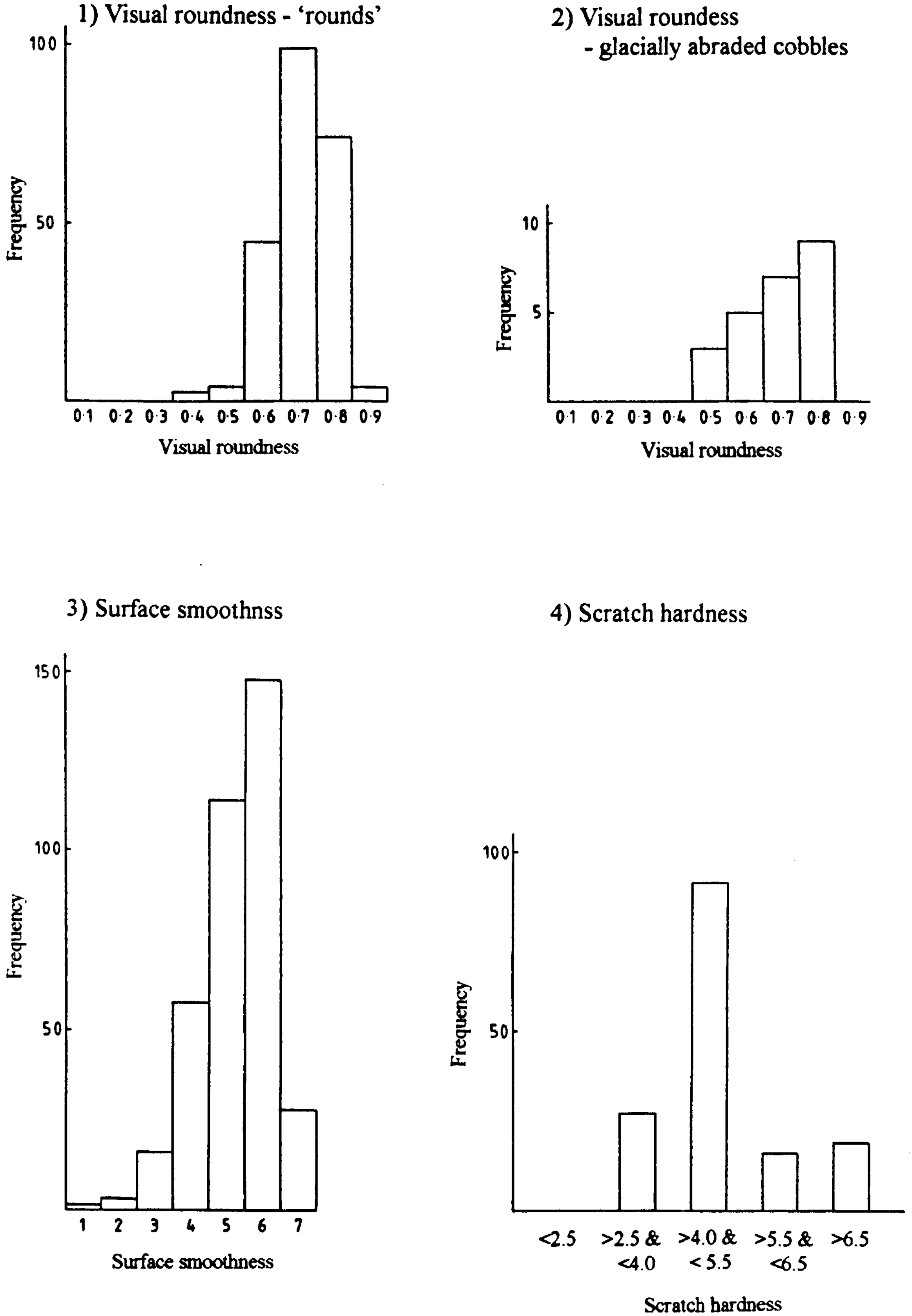


Figure 7.18 Histograms of the morphological and physical properties for the Copa Hill assemblage.

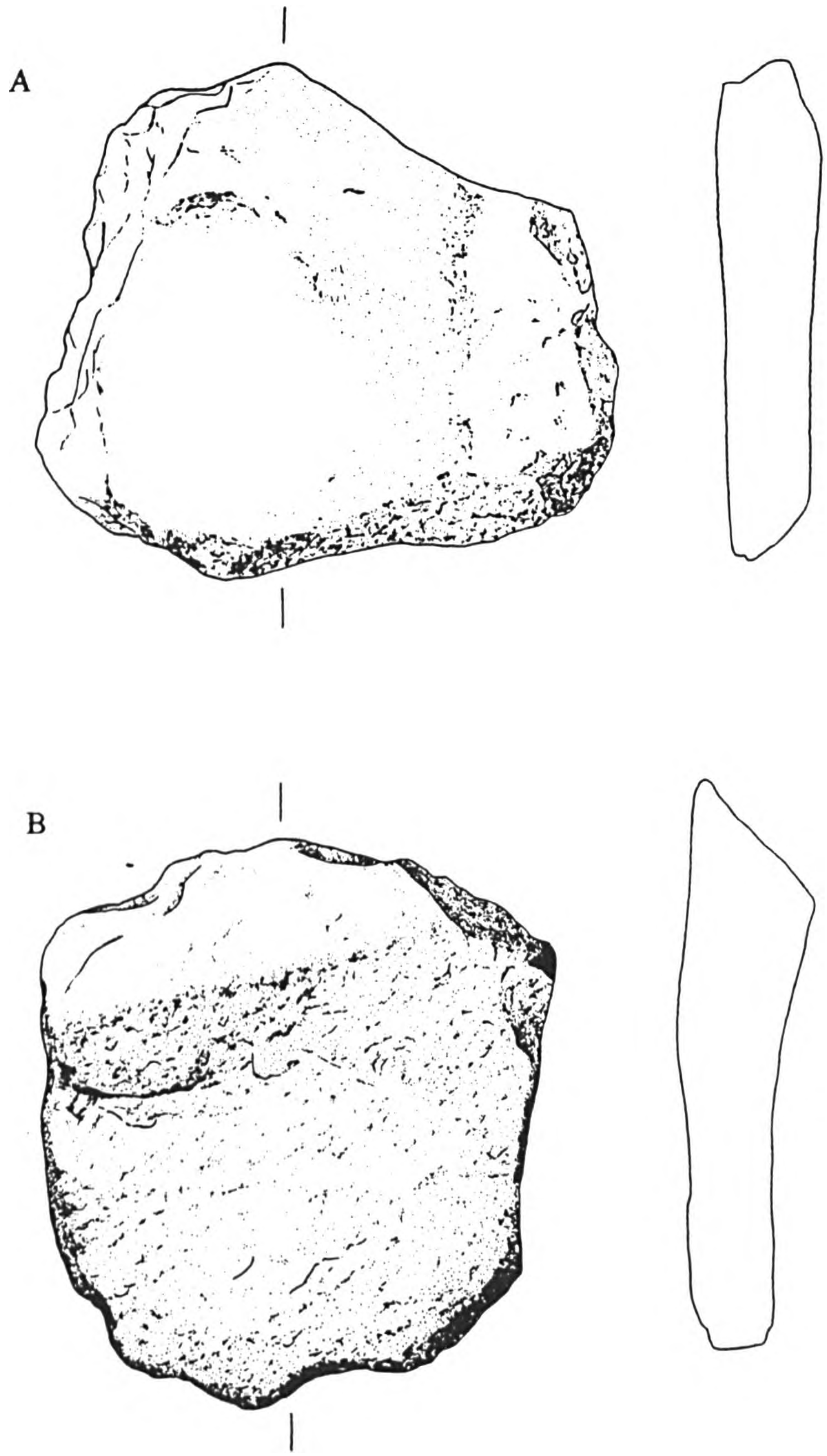


Figure 7.19 Discs from Copa Hill: A - COP.379, and B - COP.370. Scale 1:2.

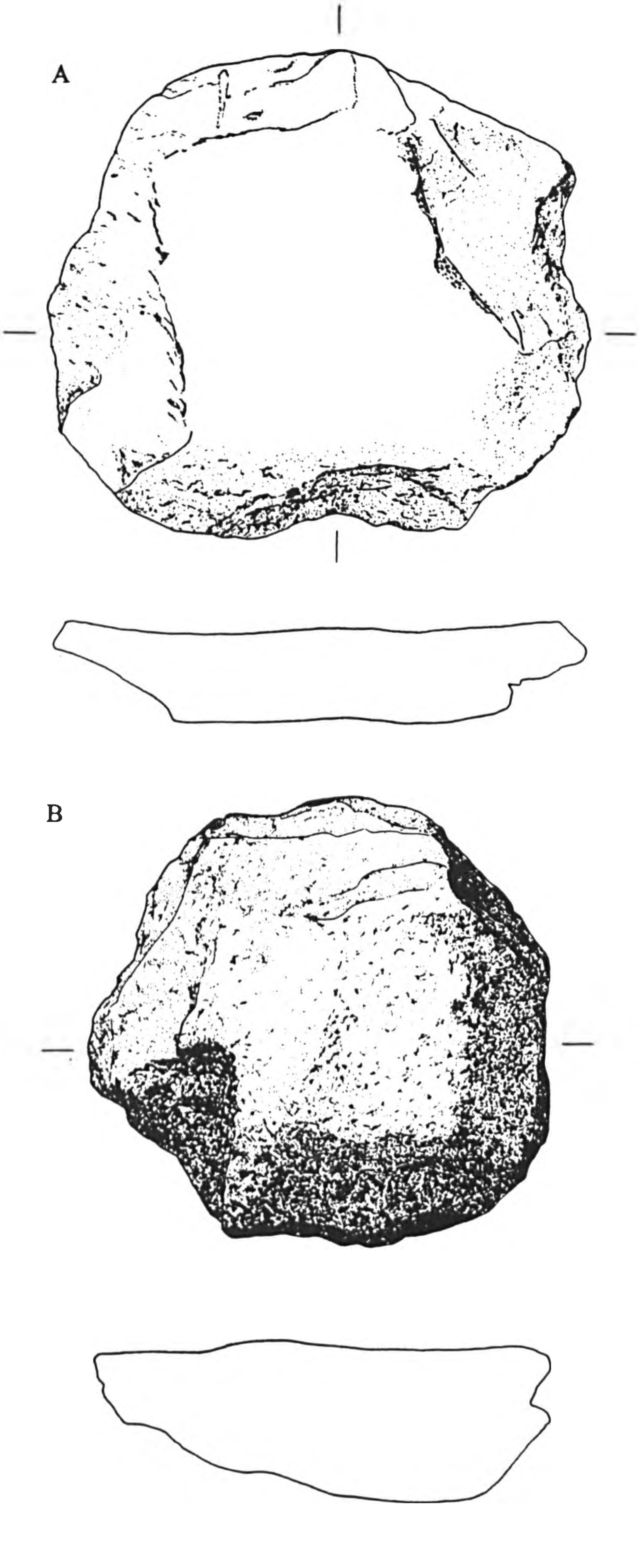


Figure 7.20 Discs from Copa Hill: A - COP.380, and B - COP.369. Scale 1:2.

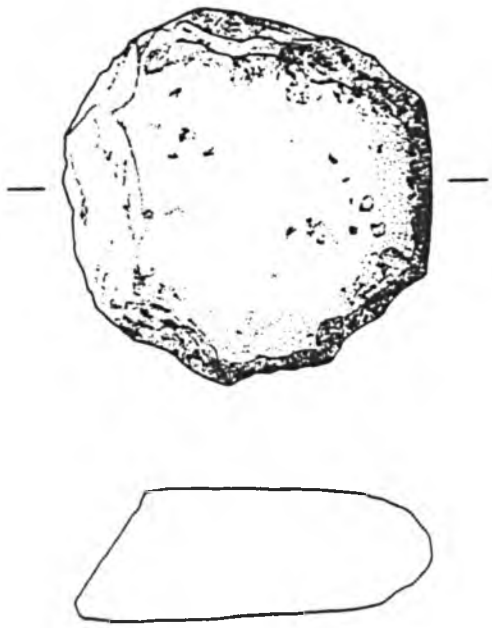


Figure 7.21 Disc (COP.328) from Copa Hill. Scale 1:2.

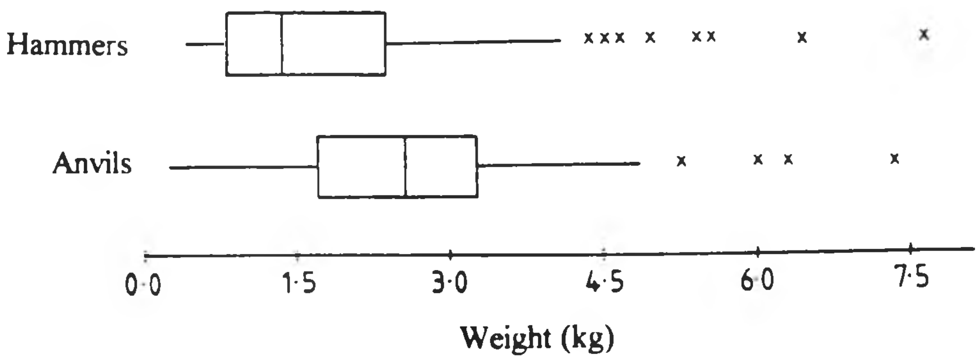


Figure 7.22 Box plots comparing the weights of hammers employed as anvils (both primary and secondary) and discarded hammers for the Copa Hill Assemblage.

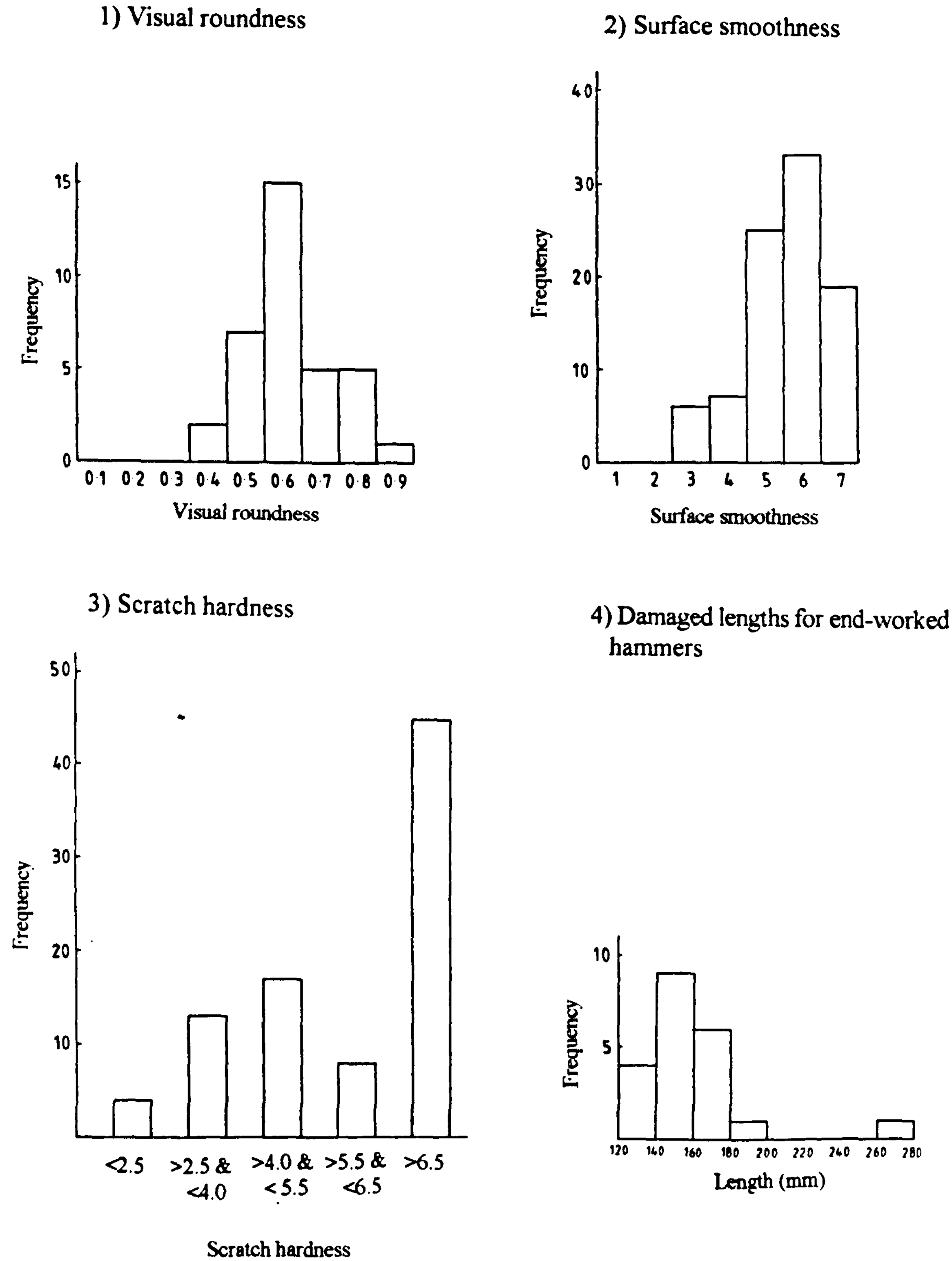


Figure 7.23 Histograms of morphological and physical properties for the Parys Mountain assemblage.

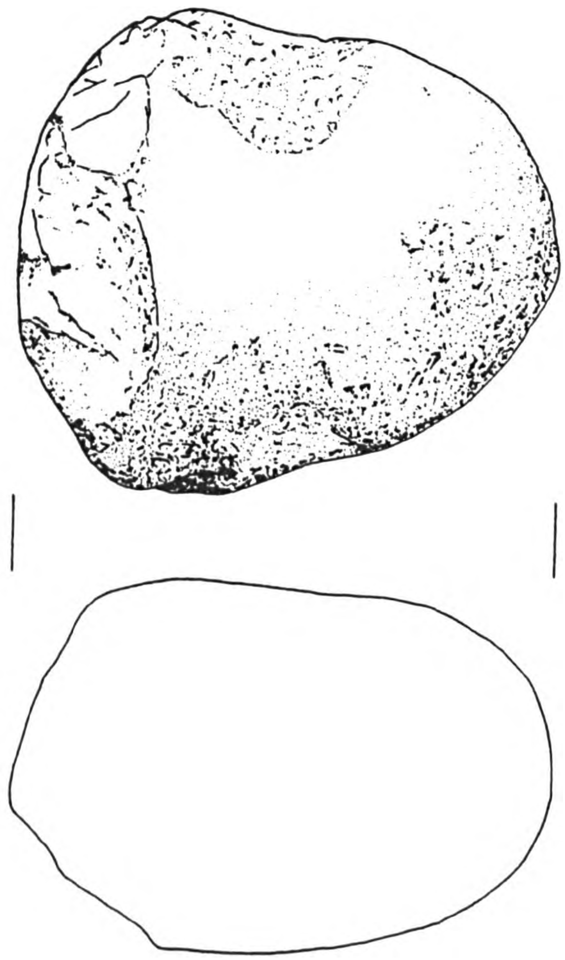


Figure 7.24 Modified hammer (grooved) from Parys Mountain - PAR.001. Scale 1:2.

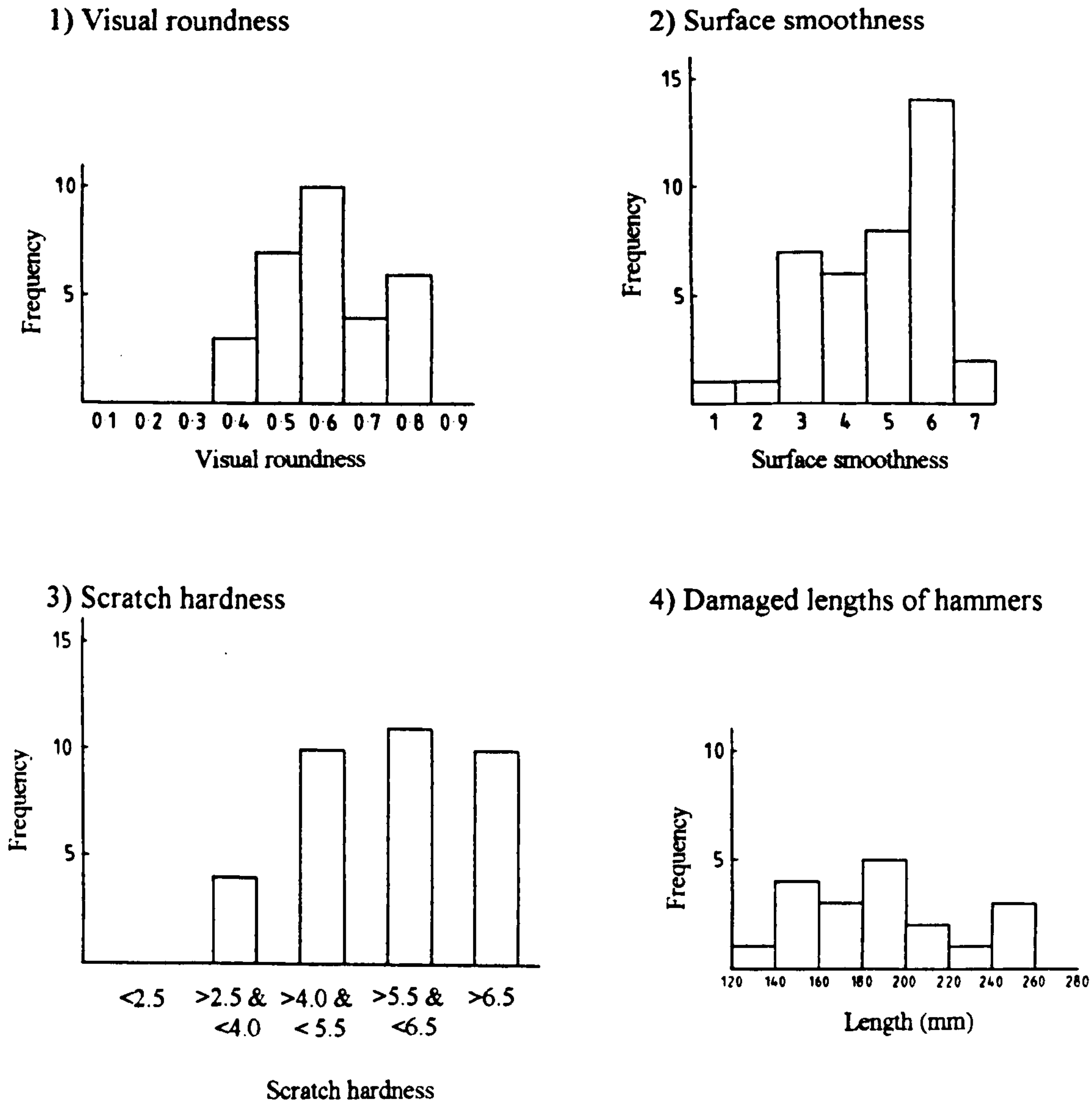


Figure 7.25 Histograms of morphological and physical properties for the Nantyreira assemblage.

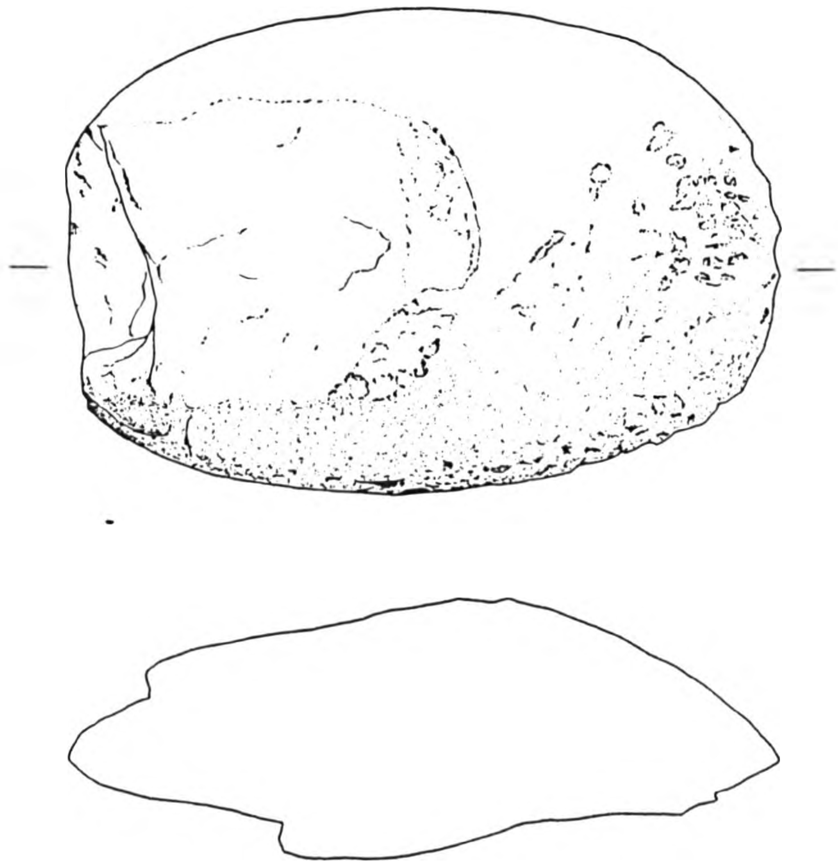
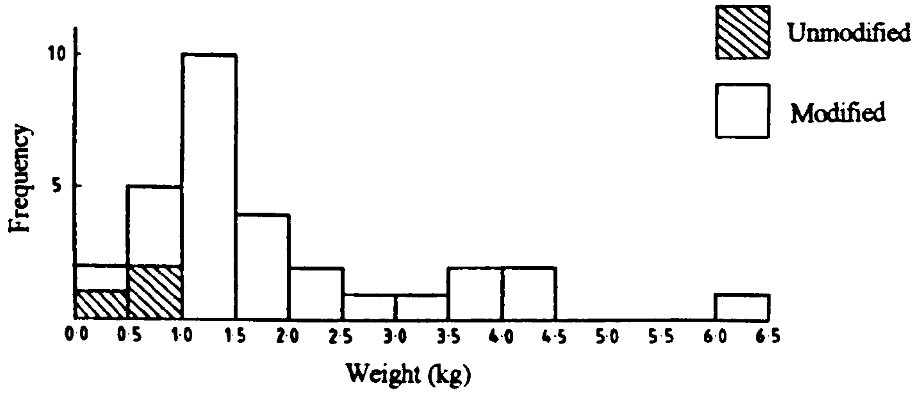
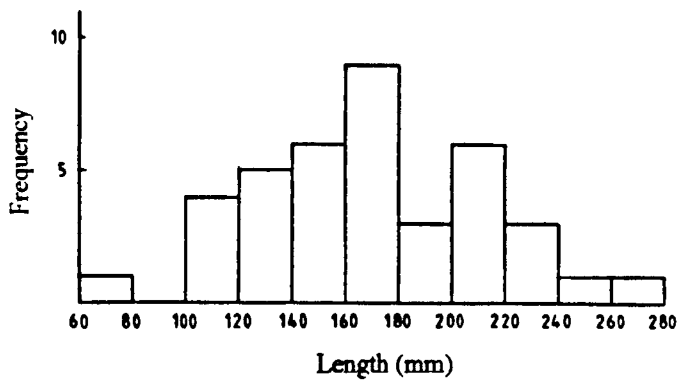


Figure 7.26 Hammer (NRE.002) from Nantyreira. Note the pound marks on the face, offset to one end, some of which are stria-like and aligned. Scale 1:2.

1) Weights of undamaged hammers



2) Undamaged lengths



3) Damaged lengths

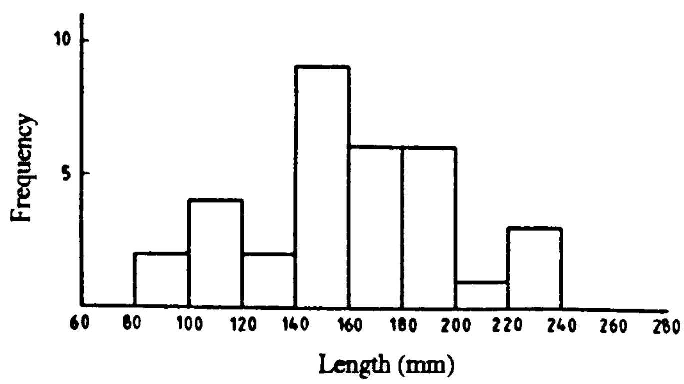


Figure 7.27 Size histograms for Alderley Edge hammers.

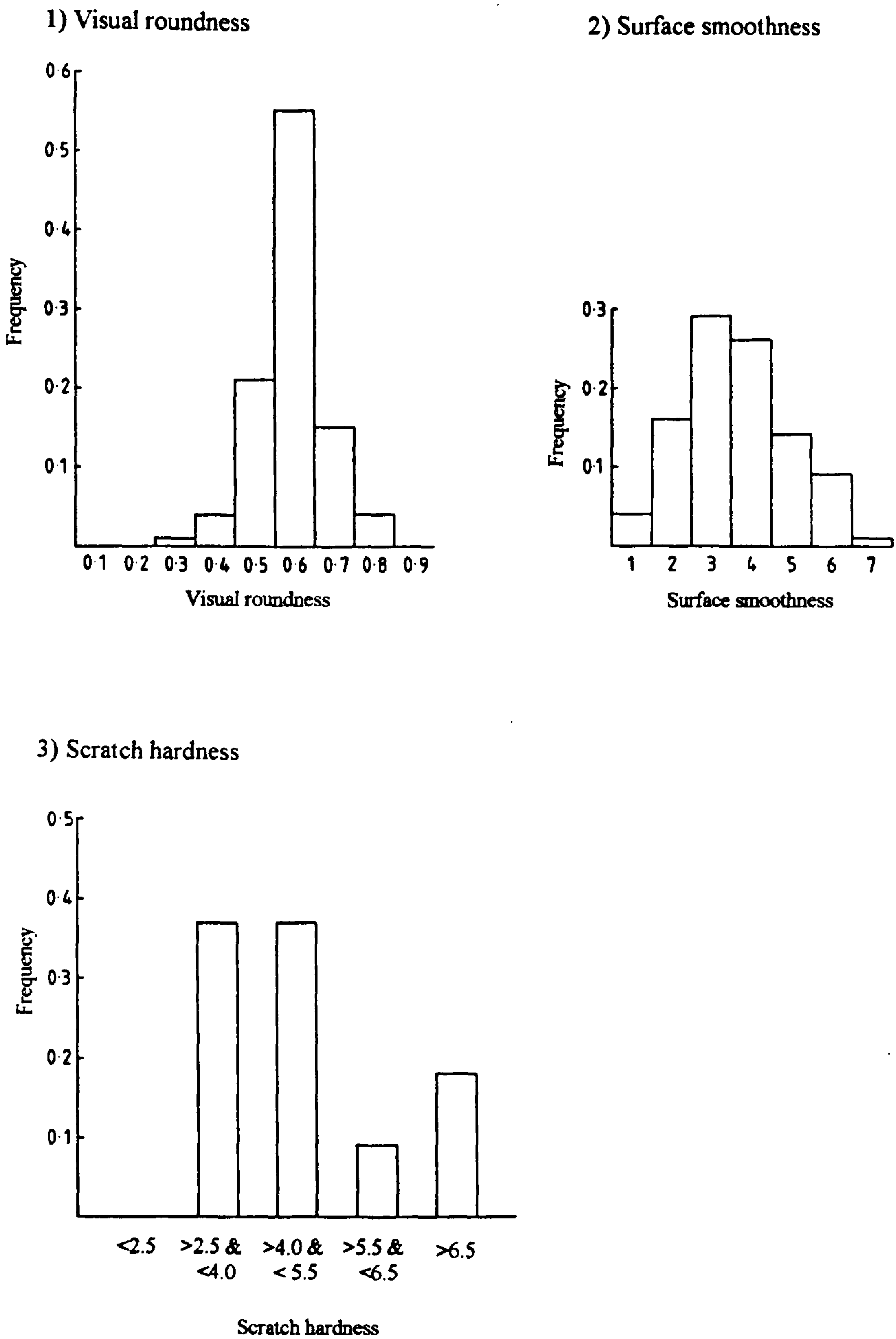


Figure 7.28 Histograms of the morphological and physical properties for the Alderley Edge assemblage.

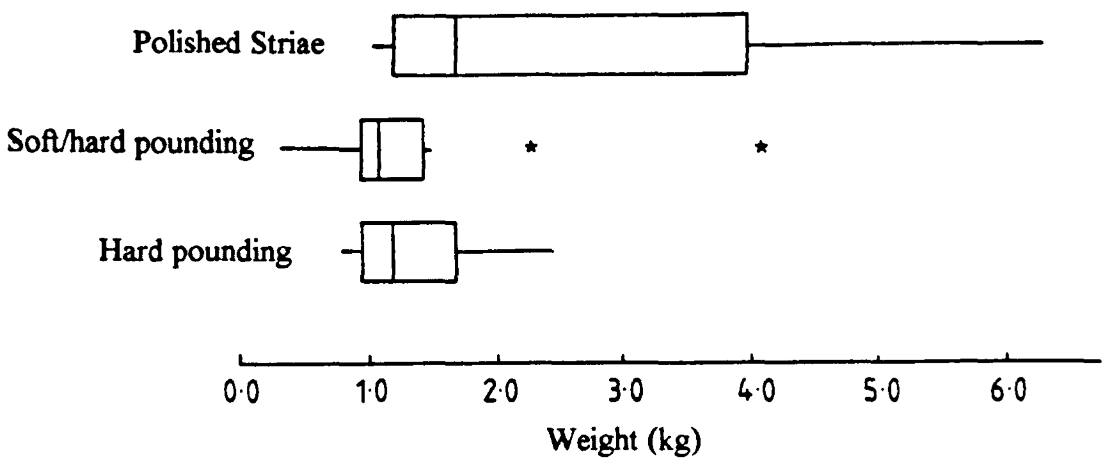


Figure 7.29 Box plots of the size of end-worked hammers from Alderley Edge according to use-wear type.

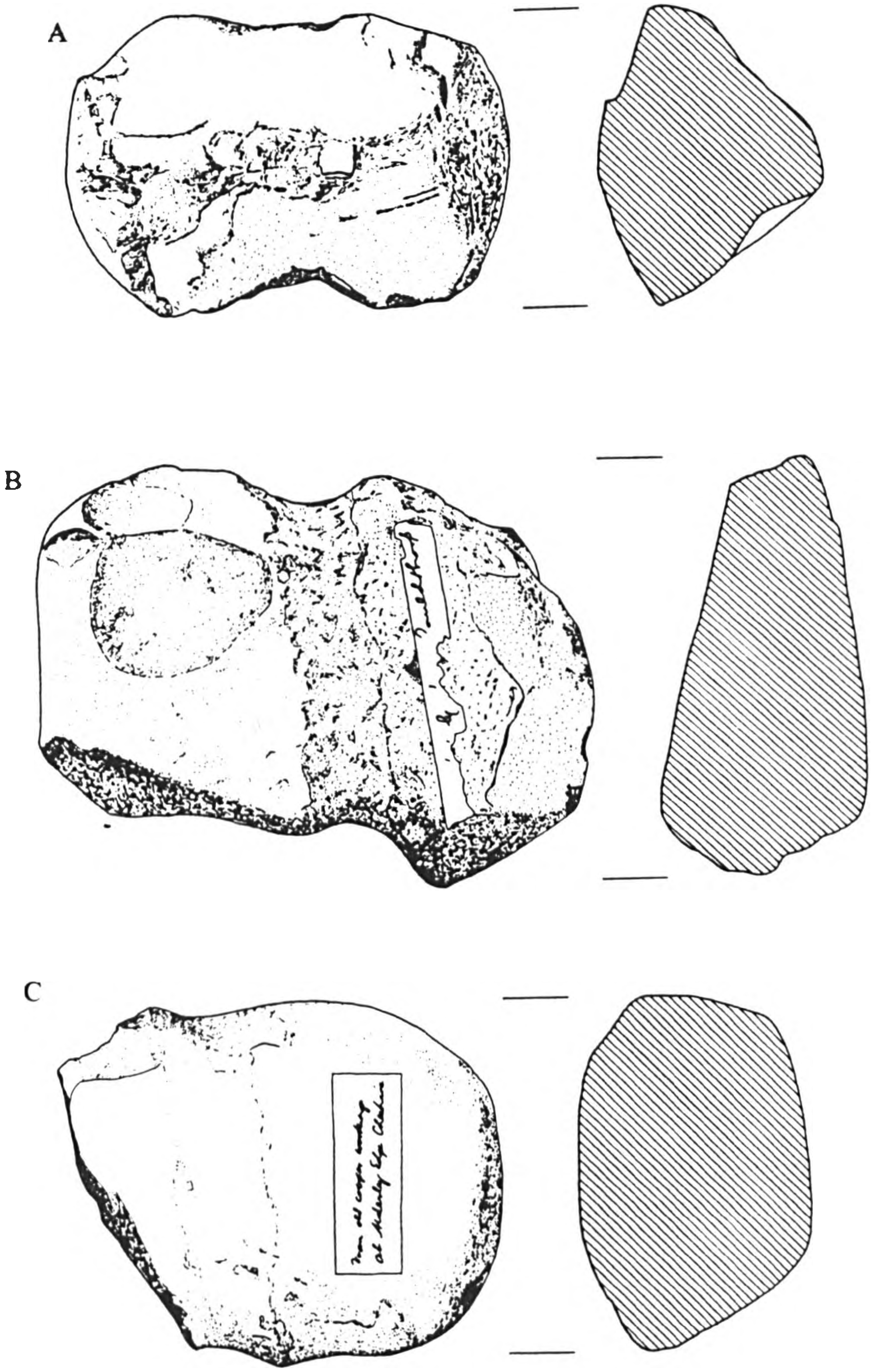


Figure 7.30 Modified hammers from Alderley Edge: A - ALD.080, edges modified by notch and surface abrasion; B - ALD.083, complete groove; C - ALD.086, grooved (damaged). Scale 1:2

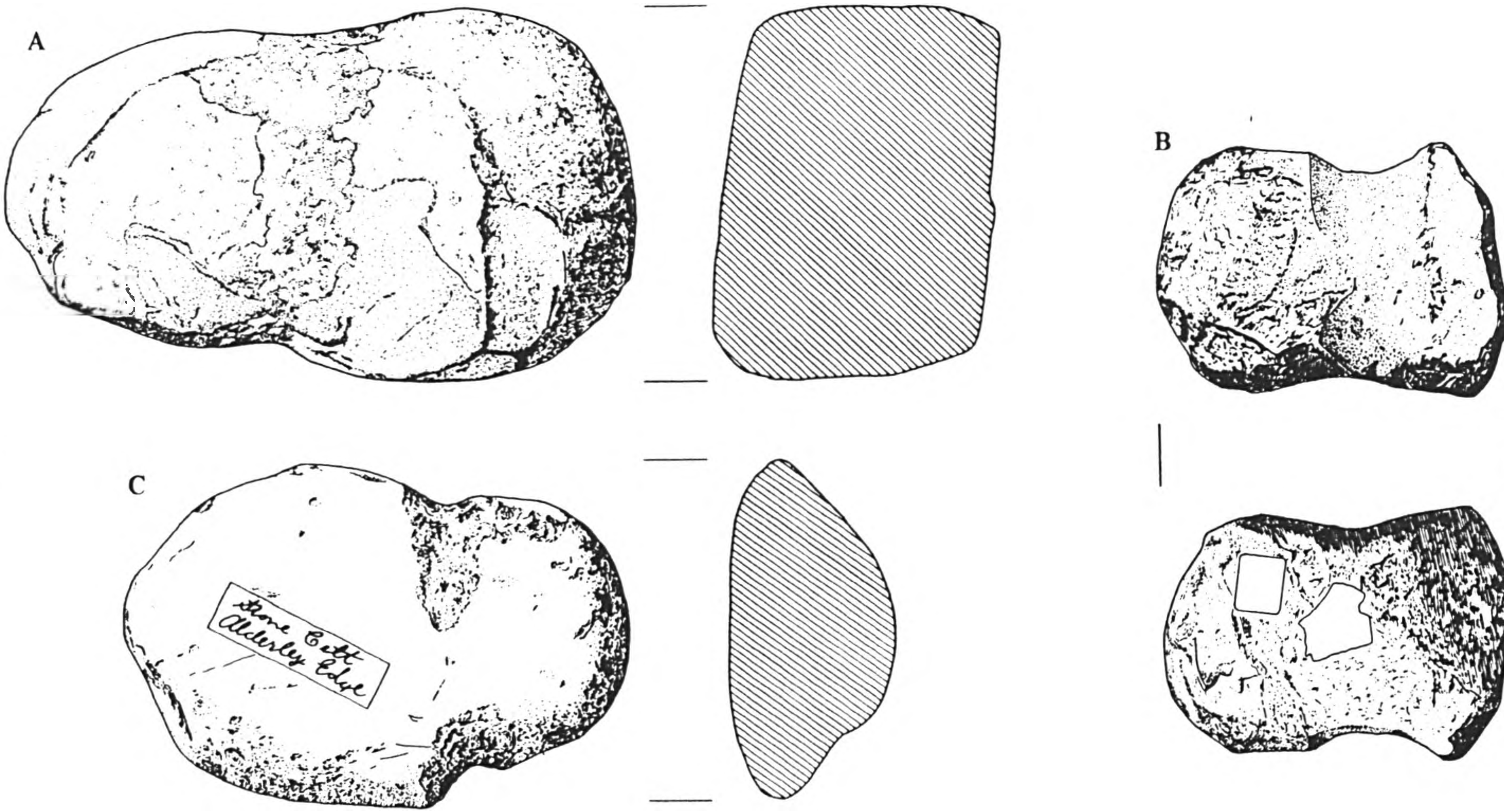


Figure 7.31 Modified hammers from Alderley Edge: A - ALD.081, unused cobble modified with a C groove; B - ALD.069, initially grooved and, on fracture, notched on the edge; C - ALD. 085, modified with an edge groove and notch. Scale 1:2.

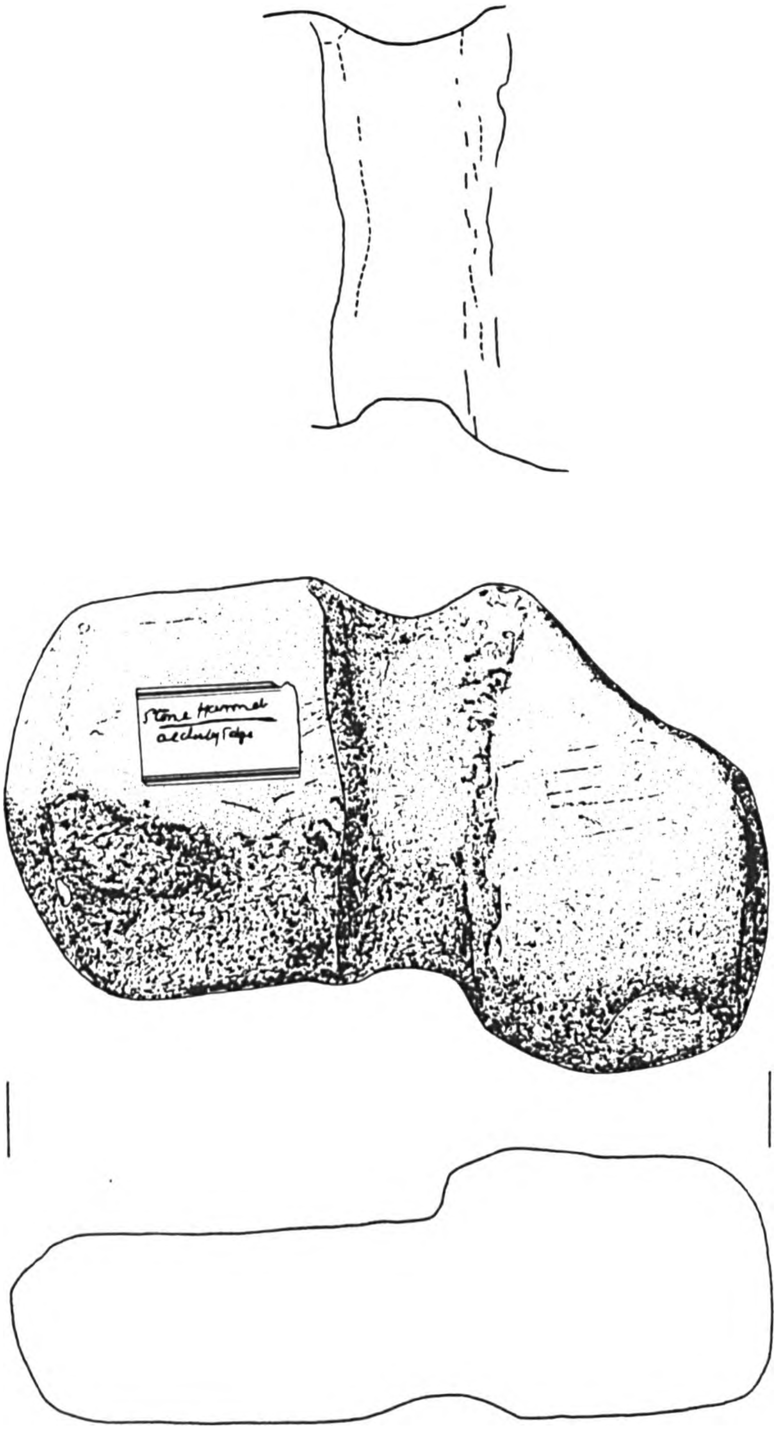


Figure 7.32 Modified hammer from Alderley Edge (ALD.006) with faceting within the modification groove (damaged) indicated. Scale 1:2.

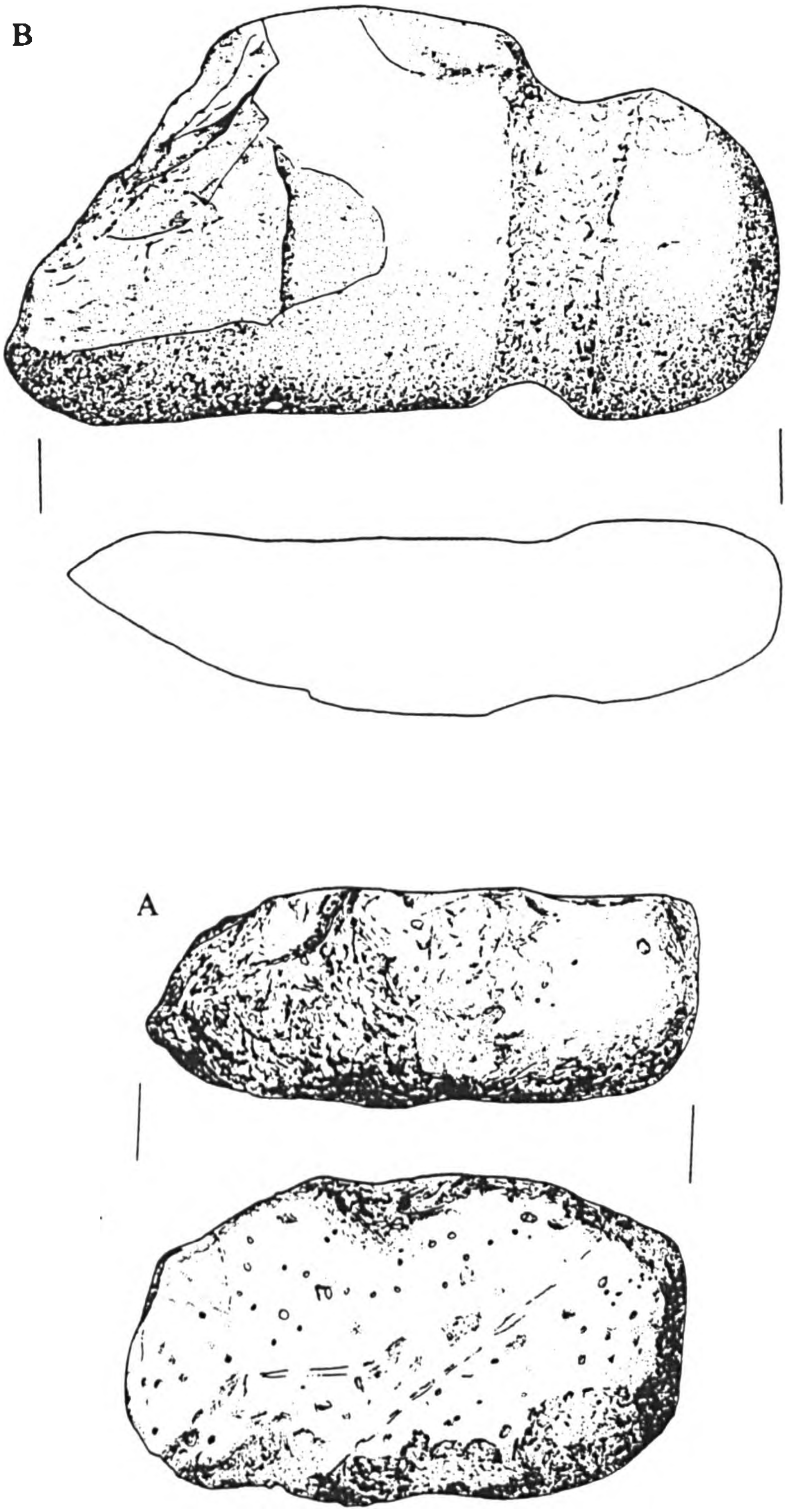


Figure 7.33 Modified hammers from Alderley Edge: A - ALD.084, edges modified with shallow notches, B - ALD.007, modified with a complete groove. Scale 1:2.

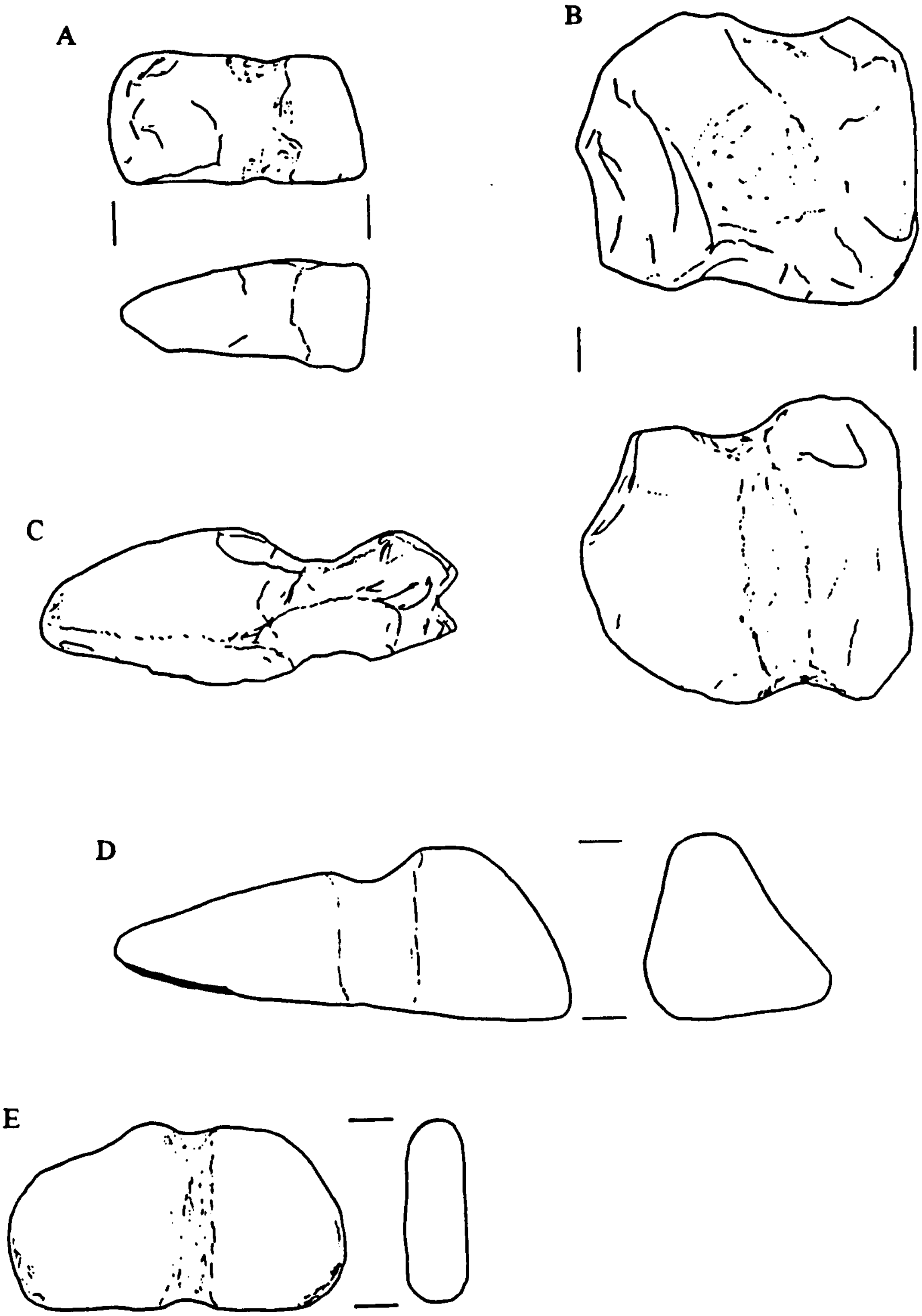


Figure 7.34 Modified (grooved) hammers from Alderley Edge: A - ALD.070; B - ALD.071; C - ALD.074, note V-shaped end groove in lateral position; D - ALD.076; E - ALD.072. Scale 1:3.

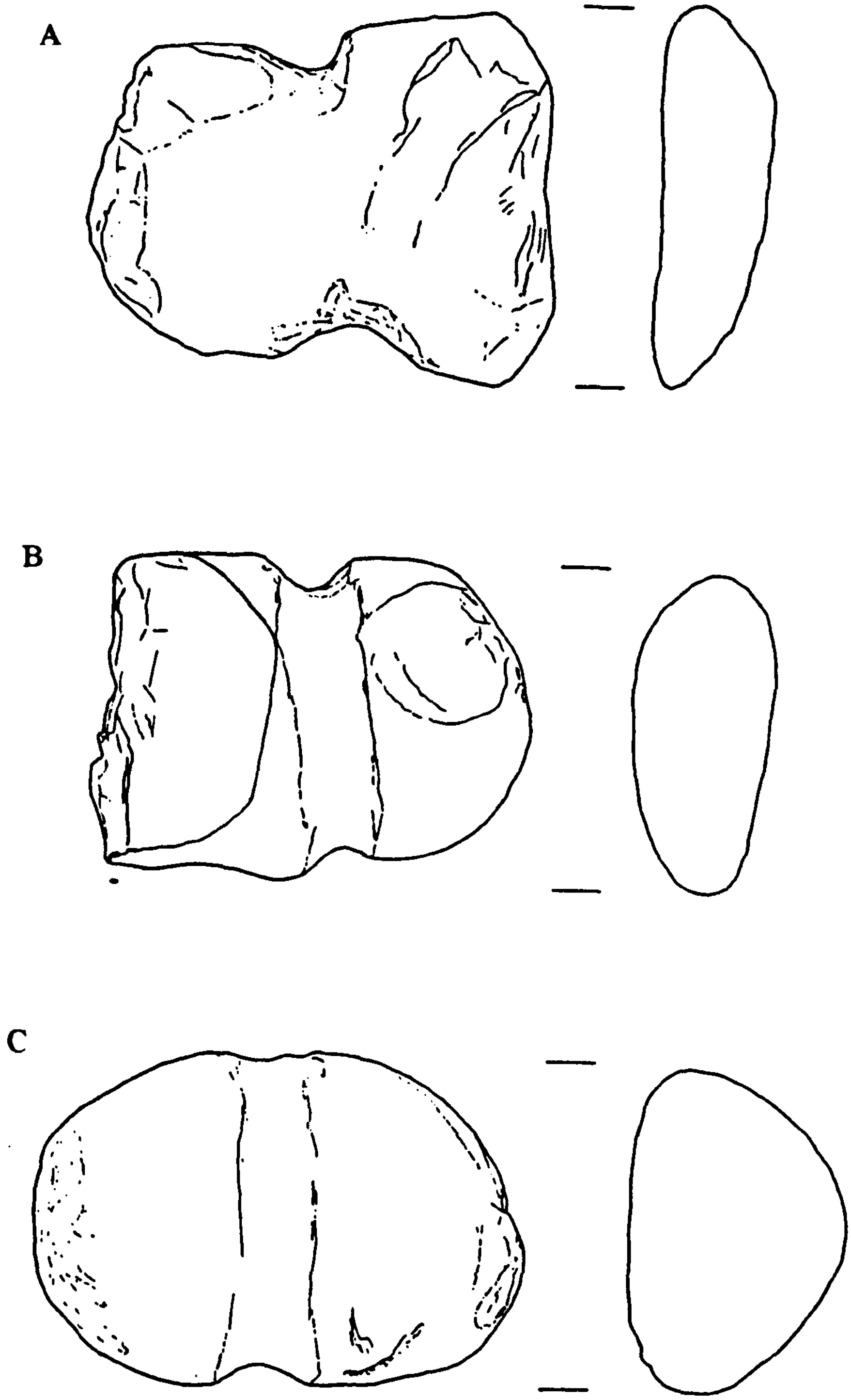


Figure 7.35 Modified hammers from Alderley Edge: A - ALD.077, notched; B - ALD.078, grooved; C - ALD.079, grooved. Scale 1:2.

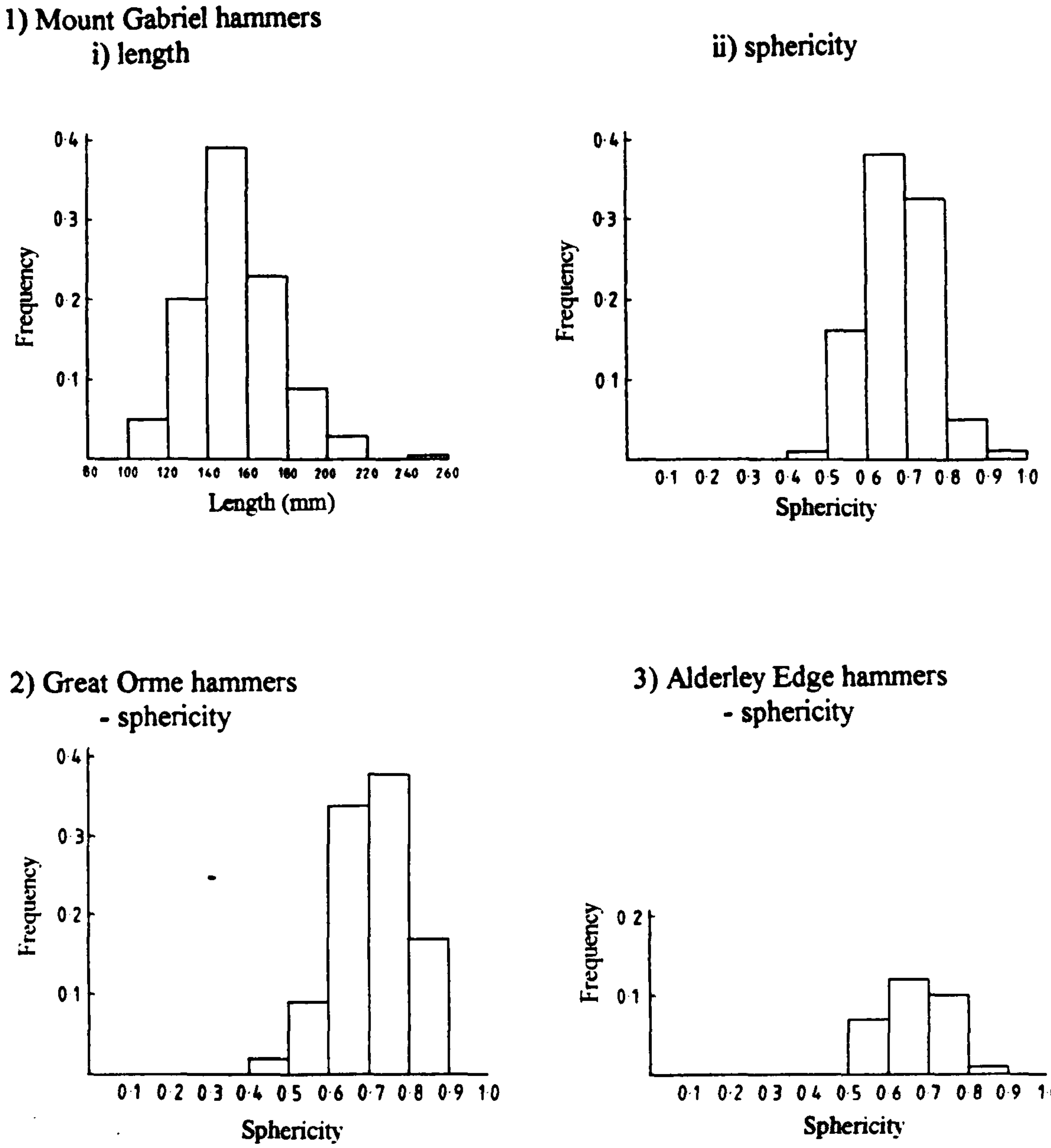


Figure 7.36 Comparison of cobble morphology for the hammers from Great Orme and Alderley Edge with the material from Mount Gabriel (after O'Brien 1994, Fig 5.7).

Rock types	Cobbles	Hammers	Modified hammers	Mortars	Anvils	Pounders & cobbing hammers	Tool fragments & spalls	Others	Totals
<u>Sedimentary</u>									
Grit	-	7	-	-	-	-	-	-	7
Sandstone/grit	-	1	-	-	1	-	-	-	2
Sandstone	1	3	-	-	-	1	-	-	4
Quartzitic sandstone	-	1	-	-	1	-	-	-	2
Quartzite/sandstone	-	2	1	-	1	1	-	-	5
Calcareous sandstone	1	1	-	-	-	-	1	-	3
Silty sandstone	-	1	-	-	-	(1)	-	-	1 (1)
Sandy siltstone	-	1	-	-	-	-	-	-	1
Siltstone	-	4	1	-	-	1	1	-	7
Mudstone	1	3	1	-	-	-	-	-	5
Limestone	1 (1)	11 (1)	-	-	(1)	2	1	1	16 (3)
<u>Igneous</u>									
Granite	-	5	2	-	-	-	1	-	8
Diorite	-	4	-	-	-	-	-	(1)	4 (1)
Gabbro	-	1	-	1	-	-	-	-	2
Microgranite	-	5 (1)	-	-	-	-	-	-	5 (1)
Microgranite/rhyolite	-	-	-	1	-	-	-	-	1
Microdiorite/diorite	-	5	-	1	-	-	-	-	6
Microdiorite	-	16	-	5	-	-	-	1	22
Dolerite	4	18	3	-	1	1	-	-	27
Dolerite/gabbro	-	1	-	-	-	-	-	-	1
Rhyolite	-	6 (1)	1	1	-	-	-	-	8 (1)
Rhyolitic tuff	1	6	-	-	-	-	-	-	7
Rhyolitic tuff/rhyolite	-	2	-	-	-	-	-	-	2
Basalt	-	4	2	-	-	-	1	-	7

N.B. Uncertain attributions in parentheses.

Table 7.1 Rock types for stone tools from the Great Orme (identifications by A. Lewis and F. Jowett).

Rock types	Cobbles	Hammers	Modified hammers	Mortars	Anvils	Pounders & cobbing hammers	Tool fragment s & spalls	Others	Totals
<u>Igneous</u>									
Greenstone	-	2	-	-	-	-	-	-	2
Porphyry	-	1	-	-	-	-	-	-	1
<u>Pyroclastic</u>									
Pyroclastic	6 (1)	30 (1)	-	-	1	-	1	1	39 (2)
Agglomerate	-	1	-	-	-	-	-	-	1
Tuff	-	1	-	-	-	-	1	-	2
Quartzitic tuff	-	1	-	-	-	-	-	-	1
Porphyritic tuff	-	-	-	-	-	-	1	-	1
<u>Metamorphic</u>									
Slate	-	1	-	-	-	-	-	-	1
Quartzite	-	5	-	-	-	-	-	-	5
Totals	15 (2)	149 (4)	11	9	5 (1)	6 (1)	8	3 (1)	206 (9)

N.B. Uncertain attributions in parentheses.

Table 7.1 (Continued) Rock types for stone tools from the Great Orme (identifications by A. Lewis and F. Jowett).

Texture/condition	Great Orme	Copa Hill	Parys Mountain	Nantyreira	Alderley Edge
Striae	21 (5.9)	33 (8.8)	4 (4.4)	4 (10.3)	41 (46.1)
Snub scars	13 (3.5)	2 (0.5)	0	1 (2.6)	5 (5.6)
Facets	18 (4.9)	6 (1.6)	4 (4.4)	1 (2.6)	19 (21.4)
Pits	95 (25.7)	15 (4.0)	33 (36.3)	14 (35.9)	16 (18.0)
Gloss	0	0	0	0	6 (6.7)
Bruise marks	1 (0.3)	2 (0.5)	0	0	0
Chink marks	239 (64.6)	214 (57.1)	48 (52.8)	27 (69.2)	46 (51.7)
Plate scars	166 (44.9)	136 (36.3)	37 (40.7)	18 (46.2)	12 (13.5)
Flake scars	26 (7.0)	6 (1.6)	3 (3.3)	12 (30.8)	40 (44.9)
Fracture	9 (2.4)	10 (2.7)	2 (2.2)	6 (15.4)	16 (18.0)
Cracks	0	1 (0.3)	0	0	0
Surface weathering	0	0	0	0	6 (6.7)
Exfoliation	0	0	0	1 (2.6)	2 (2.2)
Broken rounds	1 (0.3)	2 (0.5)	0	0	6 (6.7)

NB Relative frequencies in parentheses.

Table 7.2 Frequencies of natural surface textures and conditions for stone tools.

1) Glacially abraded cobbles

	Mean	St. dev.*	Median	Number
b/a	0.74	0.12	-	27
c/b	0.69	0.13	-	28
c/a	0.51	0.12	-	26
Rk	0.53	0.28	-	29
Rxs	0.37	0.12	-	29
Rmax	0.94	0.41	-	39
Rmin	0.64	0.29	-	39
Visual roundness	-	-	0.6	32
Weight	-	-	0.72	28
Surface smoothness	-	-	4	29

2) Other rounds

	Mean	St. dev.*	Median	Number
b/a	0.76	0.12	-	205
c/b	0.69	0.15	-	225
c/a	0.51	0.12	-	197
Rk	0.69	0.20	-	244
Rxs	0.54	0.18	-	245
Rmax	0.90	0.36	-	307
Rmin	0.73	0.21	-	288
Visual roundness	-	-	0.7	323
Weight	-	-	3.36	216
Surface smoothness	-	-	6	293

3) Subrounded limestone

	Mean	St. dev.*	Median	Number
b/a	0.74	0.12	-	6
c/b	0.73	0.15	-	6
c/a	0.56	0.15	-	8
Rk	0.35	0.20	-	6
Rxs	0.39	0.23	-	9
Rmax	0.74	0.36	-	6
Rmin	0.35	0.22	-	10
Visual roundness	-	-	0.5	9
Weight	-	-	0.9	5
Surface smoothness	-	-	3	9

* Standard deviation

Table 7.3 Morphological data for cobble types used as mining tools at the Great Orme.

	t-test*	F-test	Mann-Whitney U-test†
b/a	t = 0.61 (33) p = 0.27	F = 1.10 (204, 26) p = 0.40	-
c/b	t = 0.10 (36) p = 0.45	F = 1.35 (224, 27) p = 0.18	-
c/a	t = 0.01 (31) p = 0.50	F = 1.02 (196, 25) p = 0.36	-
Rk	t = 3.02 (31) p = 0.0025	F = 2.09 (243, 28) p = 0.0015	-
Rxs	t = 6.43 (42) p = < 0.0001	F = 1.96 (244, 28) p = 0.018	-
Rmax	t = 0.62 (45) p = 0.27	F = 1.29 (38, 306) p = 0.14	-
Rmin	t = 2.13 (44) p = 0.019	F = 1.62 (38, 287) p = 0.015	-
Weight	-	-	W = 2245.5 p = 0.0008

*One-tailed test for two independant samples, separate variance estimate.
†One-tailed test.

Table 7.4 Statistical comparison of shape and size for glacially abraded and rounded cobbles used as stone tools at the Great Orme.

Chi-Square Test for Independence

Ho: Glacially abraded cobble tools are identical in shape to other utilized cobbles.
H_1: Glacially abraded cobble tools are different in shape to other utilized cobbles.

	Convex	Flat	Concave	Totals
Glacial cobbles	9 (18.43)	18 (9.44)	5 (4.13)	32
Other cobbles	192 (182.57)	85 (93.56)	40 (40.87)	317
Totals	201	103	45	349

Expected frequencies in parentheses.

$X^2 = 14.049$ (2 degrees of freedom)
$X^2(0.05) = 5.991$

Conclusion. Observed value of X^2 is in the critical region, therefore, we reject Ho.

Table 7.5 Comparison of shape forms for glacial and non-glacial cobble tools from the Great Orme.

1) Unutilized cobbles

	Mean	St. dev.	Median	Number
b/a	0.76	0.11	-	27
c/b	0.67	0.15	-	27
c/a	0.50	0.11	-	27
Rk	0.67	0.17	-	27
Rxs	0.54	0.15	-	27
Weight	3.29	4.20	1.68	27
Visual roundness	-	-	0.7	27
Surface smoothness	-	-	6	25

2) Utilized cobbles

	Mean	St. dev.	Median	Number
b/a	0.75	0.12	-	178
c/b	0.69	0.15	-	198
c/a	0.52	0.12	-	170
Rk	0.70	0.20	-	217
Rxs	0.54	0.18	-	218
Weight	4.48	4.49	3.60	189
Visual roundness	-	-	0.7	296
Surface smoothness	-	-	6	268

N.B. Glacially abraded and subangular and subrounded limestone cobbles not included.

Table 7.6 Morphological data for utilized and unutilized cobbles from the Great Orme.

	Very soft pounding	Soft pounding	Hard pounding	Severe pounding	Flaking	Fracture
Very soft pounding	1.0000	0.0264 p = 0.364	- 0.2571 **p = < 0.001**	- 0.1476 **p = 0.026**	- 0.1633 **p = 0.015**	- 0.0772 p = 0.155
Soft pounding	-	1.0000	0.2424 **p = 0.001**	- 0.3269 **p = < 0.001**	0.0534 p = 0.241	- 0.0715 p = 0.174
Hard pounding	-	-	1.0000	0.2045 **p = 0.003**	0.3402 **p = < 0.001**	0.1471 **p = 0.026**
Severe pounding	-	-	-	1.0000	0.1872 **p = 0.007**	0.1664 **p = 0.014**
Flaking	-	-	-	-	1.0000	0.0966 p = 0.102
Fracture	-	-	-	-	-	1.0000

n = 175

Table 7.7 Correlation matrix for use-wear types of undamaged end-worked hammers from the Great Orme.

Hammer type	Number	Median	Mean	Standard deviation
Very soft/soft	15	1.45	1.93	1.96
Soft	22	1.02	1.79	1.98
Soft/hard	64	1.60	3.47	3.25
Hard	23	6.05	6.60	5.81
Hard plus	43	5.90	6.20	3.66
Severe plus	12	9.65	9.98	7.25

Table 7.8 Weight data for the Great Orme end-worked hammers categorized according to dominant use-wear type.

	End-worked hammers - unmodified				End-worked hammers - modified				End-worked hammers - possible modifications			
	Number	Median	Mean	St. dev.	Number	Median	Mean	St. dev.	Number	Median	Mean	St. dev.
Visual roundness	250	0.70	-	-	14	0.70	-	-	13	0.70	-	-
Surface smoothness	230	5	-	-	12	5	-	-	10	5	-	-
b/a	158	-	0.76	0.11	6	-	0.59	0.09	9	-	0.74	0.13
c/b	173	-	0.71	0.14	10	-	0.70	0.08	9	-	0.70	0.13
c/a	149	-	0.52	0.11	6	-	0.43	0.10	8	-	0.52	0.06
Rk	193	-	0.66	0.20	10	-	0.66	0.24	10	-	0.71	0.25
Rxs	187	-	0.51	0.17	11	-	0.57	0.24	9	-	0.51	0.19
Rmax - worked ends	315	-	0.90	0.37	16	-	0.89	0.30	13	-	0.85	0.23
Rmin - worked ends	302	-	0.71	0.22	15	-	0.78	0.22	12	-	0.60	0.25

	Edge-worked pounders				Pounders & cobbing stones				Anvils			
	Number	Median	Mean	St. dev.	Number	Median	Mean	St. dev.	Number	Median	Mean	St. dev.
Visual roundness	12	0.70	-	-	12	0.80	-	-	8	0.65	-	-
Surface smoothness	11	5	-	-	9	5	-	-	8	6	-	-
b/a	6	-	0.89	0.08	11	-	0.90	0.07	6	-	0.80	0.11
c/b	6	-	0.63	0.21	11	-	0.73	0.12	6	-	0.65	0.13
c/a	8	-	0.55	0.17	11	-	0.66	0.12	6	-	0.53	0.12
Rk	6	-	0.78	0.24	11	-	0.88	0.29	6	-	0.56	0.33
Rxs	9	-	0.49	0.29	10	-	0.69	0.20	7	-	0.51	0.13

Table 7.9 Morphological data for stone tools from the Great Orme.

	Mortars				Tool fragments & spalls	
	Number	Median	Mean	St. dev.	Number	Median
Visual roundness	10	0.7	-	-	8	0.7
Surface smoothness	5	4	-	-	13	6
b/a	5	-	0.83	0.10	-	-
c/b	7	-	0.42	0.10	-	-
c/a	6	-	0.35	0.08	-	-
Rk	6	-	0.49	0.23	-	-
Rxs	13	-	0.53	0.23	-	-

Table 7.9 (Continued) Morphological data for stone tools from the Great Orme.

	Number	Median	Minimum	Maximum
Unmodified end-worked hammers	169	3.62	0.18	29.00
Modified end-worked hammers	8	0.92	0.53	4.5 (7.65)
End-worked hammers - possible modifications	10	2.72	0.53	20.00
Edge-worked hammers	6	0.85	0.33	5.5 (29.00)
Mortars	5	9.75	3.24	11.50
Anvils	6	6.18	1.10	15.20
Pounders and cobbers	10	0.74	0.45	1.43

N.B. Weights of damaged tools in parenthesis.

Table 7.10 Weight data (kg) for tool classes from the Great Orme.

	Unmodified hammers	Modified hammers	Possible modified hammers
Great Orme			
Simple	212	9	11
Scatter	3	0	0
Circumferential	6	0	0
Faceted	9	3	2
Notched	11	1	0
Offset/normal	29/215	3/10	2/11
Number	279	14	14
Copa Hill			
Simple	150	14	20
Scatter	0	0	0
Circumferential	2	0	0
Faceted	8	1	0
Notched	10	0	0
Offset/normal	47/119	4/10	5/14
Number	240	18	21
Parys Mountain			
Simple	21	3	7
Scatter	0	0	0
Circumferential	0	0	0
Faceted	0	0	0
Notched	1	0	1
Offset/normal	0/20	1/2	0/8
Number	37	3	11
Nantyreira			
Simple	19	3	1
Scatter	0	0	0
Circumferential	0	0	0
Faceted	1	0	0
Notched	2	0	0
Offset/normal	5/20	1/2	1/1
Number	30	3	4
Alderley Edge			
Simple	5	57	-
Scatter	0	0	-
Circumferential	0	2	-
Faceted	1	3	-
Notched	0	3	-
Offset/normal	0/6	8/63	-/-
Number	6	79	0

Table 7.11 Primary use-wear features for end-working of hammers.

1) Unmodified

i) Two-ended cobbles

		Other end				
		None	Scant	Trace	Minor	Major
One end	None	0	4	19	8	6
	Scant	-	1	2	0	0
	Trace	-	-	23	28	5
	Minor	-	-	-	17	30
	Major	-	-	-	-	54

i) Single surviving ends

None	0
Scant	1
Trace	4
Minor	12
Major	11

2) Modified

i) Two-ended cobbles

		Other end				
		None	Scant	Trace	Minor	Major
One end	None	0	0	1	0	0
	Scant	-	0	0	0	0
	Trace	-	-	0	3	0
	Minor	-	-	-	1	5
	Major	-	-	-	-	3

ii) Single surviving ends

None	0
Scant	0
Trace	0
Minor	1
Major	0

3) Possible identifications

i) Two-ended cobbles

		Other end				
		None	Scant	Trace	Minor	Major
One end	None	0	0	0	1	0
	Scant	-	0	0	0	0
	Trace	-	-	1	0	1
	Minor	-	-	-	2	2
	Major	-	-	-	-	3

ii) Single surviving ends

None	0
Scant	0
Trace	0
Minor	1
Major	0

4) All end-worked hammers

i) Two-ended cobbles

		Other end				
		None	Scant	Trace	Minor	Major
One end	None	0	4 (1.8)	20 (9.1)	9 (4.1)	6 (2.7)
	Scant	-	1 (0.5)	2 (1.1)	0	0
	Trace	-	-	24 (10.9)	31 (14.1)	6 (2.7)
	Minor	-	-	-	20 (9.1)	37 (16.8)
	Major	-	-	-	-	60 (27.3)

ii) Single surviving ends

None	0
Scant	1
Trace	4
Minor	14
Major	11

Table 7.12 Intensity of use for modified and unmodified hammers from the Great Orme.

	Unmodified hammers	Modified hammers	Possible modified hammers	Edge-worked hammers	Mortars	Anvils
Great Orme						
Simple	26	-	-	5	6	1
Scatter	3	-	-	1	0	0
Discontinuous working	0	-	-	0	1	0
Continuous working	2	-	-	5	0	0
Faceted	6	-	-	0	0	0
Offset/normal	6/32	-	-	2/9	2/5	- /1
Number	39/280	0	0	11/11	8/14	1/6
Copa Hill						
Simple	8	-	0	1	-	-
Scatter	3	-	0	0	-	-
Discontinuous working	0	-	0	0	-	-
Continuous working	0	-	1	0	-	-
Faceted	0	-	0	0	-	-
Offset/normal	2/9	-	- /1	1/ -	-	-
Number	12/219	0	1/21	1/1	-	-
Parys Mountain						
Simple	0	-	-	-	-	-
Scatter	1	-	-	-	-	-
Discontinuous working	0	-	-	-	-	-
Continuous working	1	-	-	-	-	-
Faceted	1	-	-	-	-	-
Offset/number	1/2	-	-	-	-	-
Number	5/37	0	0	-	-	-
Nantyreira						
Simple	0	-	-	-	-	-
Scatter	0	-	-	-	-	-
Discontinuous working	0	-	-	-	-	-
Continuous working	1	-	-	-	-	-
Faceted	0	-	-	-	-	-
Offset/normal	- /1	-	-	-	-	-
Number	1/30	0	0	-	-	-
Alderley Edge						
Simple	0	1	-	-	-	-
Scatter	0	1	-	-	-	-
Discontinuous working	0	0	-	-	-	-
Continuous working	1	2	-	-	-	-
Faceted	0	0	-	-	-	-
Offset/normal	- /6	1/2				
Number	1/6	4/~~81~~180	-	-	-	-

Table 7.13 Primary edge-working forms. The table gives a frequency breakdown of recordable working forms while the number row expresses the proportion of tools for each class which display edge-working.

Rock type	Pounders	Hammers	Modified hammers	Discs	Spalls	Tool fragments	Totals
Sedimentary							
Grit	-	10	-	2	-	-	12
Quartzitic grit	-	5	-	-	2	-	7
Sandstone/grit	-	4	2	-	3	-	9
Quartzitic sandstone/grit	-	2	-	-	-	-	2
Sandstone	-	9	3	1	6	1	20
Quartzitic sandstone	-	6	1	-	1	-	8
Quartzite/sandstone	-	2	-	-	3	1	6
Quartzite	1	3	-	-	1	-	5
Igneous							
Quartz porphyry	-	1*	-	-	-	-	1
Pyroclastic							
Tuff	-	1	-	-	-	-	1
Totals	1	43	6	3	16	2	71

* Humphery (1989)

Table 7.14 Rock types for stone tools from Copa Hill (identifications by S. Timberlake).

1) Glacially abraded cobbles

	Mean	St. dev.	Median	Number*
Visual roundness	-	-	0.7	24 (12)
Surface smoothness	-	-	5	36
Dk (mm)	66.67	25.67	-	18 (18)
Dxs (mm)	40.50	18.56	-	20 (16)

2) Other cobbles

	Mean	St. dev.	Median	Number*
Visual roundness	-	-	0.7	233 (99)
Surface smoothness	-	-	6	332
Dk (mm)	77.63	25.23	-	126 (206)
Dxs (mm)	46.87	17.88	-	183 (149)

* Number of values missing due to damage are given in parentheses.

Table 7.15 Morphological data for glacial and non-glacial cobble tools from Copa Hill.

Chi-Square Test for Independence

Ho: Glacially abraded cobble tools are identical in shape to other utilized cobbles.
H_1: Glacially abraded cobble tools are different in shape to other utilized cobbles.

	Convex	Flat	Concave	Totals
Glacial cobbles	9	12	5	26
	(10.77)	(12.51)	(2.72)	
Other cobbles	90	103	20	213
	(88.23)	(102.49)	(22.28)	
Totals	99	115	25	239

Expected frequencies in parentheses.

$X^2 = 2.495$ (2 degrees of freedom)
$X^2(0.05) = 5.991$

Conclusion. Observed value of X^2 is not in the critical region, therefore, we accept Ho.

Table 7.16 Comparison of shape forms for glacial and non-glacial cobble tools from Copa Hill.

	Unmodified			Modified			Possible modifications		
	Number of hammers	Number of ends	Median	Number of hammers	Number of ends	Median	Number of hammers	Number of ends	Median
Surface smoothness	220	-	6	18	-	6	23	-	6
Visual roundness	199	-	0.7	16	-	0.8	21	-	0.8
Dk (mm)	115	-	80	6	-	70	15	-	80
Dxs (mm)	161	-	45.0	14	-	47.5	19	-	50.0
Dmax - worked ends (mm)	142	181	110	10	11	110	16	24	90
Dmin - worked ends (mm)	113	136	60	6	9	60	15	8	60
Depth of flake scar step terminations	78	80	2.9	10	10	2.8	12	11	2.7

Table 7.17 Morphological and use-wear data for modified and unmodified hammers from Copa Hill.

	Soft pounding	Hard pounding	Severe pounding	Flaking	Fracture
Soft pounding	1.0000	0.1712 $p = \mathbf{0.007}$	- 0.0998 $p = 0.075$	0.0638 $p = 0.180$	- 0.130 $p = 0.426$
Hard pounding	-	1.0000	0.2397 $p = < \mathbf{0.001}$	0.0498 $p = 0.237$	0.438 $p = 0.265$
Severe pounding	-	-	1.0000	0.2107 $p = \mathbf{0.001}$	0.1202 $p = \mathbf{0.041}$
Flaking	-	-	-	1.0000	0.1158 $p = \mathbf{0.047}$
Fracture	-	-	-	-	1.0000

n = 209

Table 7.18 Correlation matrix for use-wear types of end-worked hammers from Copa Hill.

1) Unmodified

i) Two-ended cobbles

		Other end				
		None	Scant	Trace	Minor	Major
One end	None	0	2	6	2	20
	Scant	-	0	0	1	3
	Trace	-	-	7	4	18
	Minor	-	-	-	6	20
	Major	-	-	-	-	17

ii) Single surviving ends

None	-
Scant	0
Trace	12
Minor	23
Major	30

2) Modified

i) Two-ended cobbles

		Other end				
		None	Scant	Trace	Minor	Major
One end	None	0	0	0	0	0
	Scant	-	0	0	0	0
	Trace	-	-	0	0	0
	Minor	-	-	-	2	4
	Major	-	-	-	-	7

ii) Single surviving ends

None	0
Scant	0
Trace	0
Minor	2
Major	1

3) Possible identifications

i) Two-ended cobbles

		Other end				
		None	Scant	Trace	Minor	Major
One end	None	0	0	1	0	1
	Scant	-	0	0	0	1
	Trace	-	-	0	0	4
	Minor	-	-	-	0	8
	Major	-	-	-	-	2

ii) Single surviving ends

None	0
Scant	0
Trace	0
Minor	2
Major	1

4) All end-worked hammers

i) Two-ended cobbles

		Other end				
			Scant	Trace	Minor	Major
One end	None	0	2 (1.5)	7 (5.1)	2 (1.5)	21 (15.4)
	Scant	-	0	0	1 (0.7)	4 (2.9)
	Trace	-	-	7 (5.1)	4 (2.9)	22 (16.2)
	Minor	-	-	-	8 (3.8)	32 (23.5)
	Major	-	-	-	-	26 (19.1)

ii) Single surviving ends

None	0
Scant	0
Trace	12
Minor	27
Major	32

Table 7.19 Intensity of use for modified and unmodified hammers from Copa Hill.

1) Hammers

	Mean	St. dev	Median	Number*
Dk (mm)	74.41	24.93	-	74 (91)
Dxs (mm)	45.18	18.80	-	114 (51)
Visual roundness	-	-	0.7	143 (22)
Surface smoothness	-	-	5	165
Weight (kg)	1.79	1.27	1.36	161

2) Anvils

	Mean	St. dev	Median	Number*
Dk (mm)	81.45	26.42	-	55 (23)
Dxs (mm)	49.59	16.46	-	68 (10)
Visual roundness	-	-	0.7	76 (2)
Surface smoothness	-	-	6	78
Weight (kg)	2.69	1.39	2.55	77

* Number of values missing due to damage in parentheses.

Table 7.20 Morphological data for hammers and stones used as anvils for Copa Hill.

Chi-Square Test for Independence

Ho: Stone tool pieces used for anvil working are identical in shape to those used solely as hammers.
H_1: Stone tool pieces used for anvil working are different in shape to those used solely as hammers.

	Convex	Flat	Concave	Totals
Hammers	57	64	12	133
	(56.17)	(65.21)	(11.62)	
Anvils	30	37	6	73
	(30.83)	(35.79)	(6.38)	
Totals	87	101	18	206

Expected frequencies in parentheses.

$X^2 = 0.133$ (2 degrees of freedom)
$X^2(0.05) = 5.991$

Conclusion. Observed value of X^2 is not in the critical region, therefore, we accept Ho.

Table 7.21 Comparison of shape forms for anvils and hammers from Copa Hill.

Rock type	Unmodified hammers	Modified hammers	Spalls and tool fragments	Discs	Rottenstones
Sedimentary					
Grit	0	0	4	0	0
Sandstone	0	0	2 (1)	0	3
Quartzite/sandstone	0	0	1	0	0
Quartzite	3	0	3	0	0
Silt/sandstone	0	0	1	0	0
Siltstone	(1)	0	2	0	0
Mudstone	0	0	(1)	0	0
Chert	0	0	1	0	0
Metamorphic					
Schist	0	0	0	1	0
Quartzite	0	0	(1)	0	0
Pyroclastic					
Ignimbrite	1	0	1	0	0
Tuff	1 (2)	0	(1)	0	0
Pyroclastic	0	0	(3)	0	0
Igneous					
Dolerite	2 (1)	0	3	0	0
Felsite	0	0	(1)	0	0
Granite	1	0	2 (1)	0	0
Microdiorite	(1)	0	0	0	0
Microgranite	2	0	(2)	0	0
Quartz	0	0	1	0	0
Quartz porphyry	2 (2)	0	1 (2)	0	0
Rhyolite	(3)	1	1 (3)	0	0
Rhyolite crystal tuff	1	0	0	0	0
Rhyolite porphyry	0	0	2	0	0
Rhyolite tuff	1	0	1	0	0
Vein quartz	2	0	2 (1)	0	0
Serpentized	2	0	0	0	0
Totals	19 (9)	1	28 (17)	1	3

N.B. Uncertain attributions in parentheses.

Table 7.22 Rock types for stone tools from Parys Mountain (identifications by S. Timberlake).

1) Parys Mountain

i) Two-ended cobbles

		Other end			
		None	Trace	Minor	Major
One end	None	0	0	3	1
	Trace	-	1	0	2
	Minor	-	-	2	5
	Major	-	-	-	7

ii) Single surviving ends

None	0
Trace	1
Minor	4
Major	11

2) Nantyreira

i) Two-ended cobbles

		Other end			
		None	Trace	Minor	Major
One end	None	0	0	1	4
	Trace	-	0	0	2
	Minor	-	-	2	10
	Major	-	-	-	1

ii) Single surviving ends

None	0
Trace	0
Minor	7
Major	2

3) Alderley Edge

Unmodified and transversely modified cobbles
i) Two-ended

		Other end			
		None	Trace	Minor	Major
One end	None	2	4	6	5
	Trace	-	4	4	4
	Minor	-	-	12	13
	Major	-	-	-	11

ii) Single-ended cobbles and single surviving ends

None	0
Trace	2
Minor	4
Major	6

iii) Hammers with lateral modification

None	0
Trace	3
Minor	2
Major	6

Table 7.23 Intensity of use for end-worked hammer types from Parys Mountain, Nantyreira and Alderley Edge.

Parys Mountain

	Soft pounding	Hard pounding	Severe pounding	Flaking	Fracture
Soft pounding	1.0000	0.2578 p = 0.071	0.0628 p = 0.362	- 0.0159 p = 0.464	-0.1240 p = 0.242
Hard pounding	-	1.0000	0.3255 **p = 0.030**	0.0167 p = 0.463	- 0.0911 p = 0.304
Severe pounding	-		1.0000	- 0.1204 p = 0.249	- 0.1533 p = 0.193
Flaking	-	-	-	1.0000	0.1204 p = 0.249
Fracture	-	-	-	-	1.0000

n = 34

Nantyreira

	Soft pounding	Hard pounding	Severe pounding	Flaking	Fracture
Soft pounding	1.0000	0.2095 p = 0.117	0.0054 p = 0.488	- 0.0913 p = 0.304	- 0.1856 p = 0.147
Hard pounding	-	1.0000	0.2112 p = 0.115	0.0963 p = 0.294	- 0.1967 0.132
Severe pounding	-	-	1.0000	0.5130 **p = 0.001**	0.3447 **p = 0.023**
Flaking	-	-	-	1.0000	0.0937 p = 0.299
Fracture	-	-	-	-	1.0000

n = 34

Table 7.24 Correlation matrices for use-wear types of end-worked hammers from Parys Mountain and Nantyreira.

Rock type	Unmodified hammers	Modified hammers	Spalls and tool fragments
Grit	3	1	0
Quartzitic arkosic grit	1	0	0
Quartzite/grit	6	10	1
Grit/sandstone	2	0	0
Quartzitic sandstone/grit	1	1	0
Quartzitic sandstone	6	0	2
Quartzite/sandstone	0	0	2
Quartzite	1	0	0
Sandstone	4	1	2
Totals	24	4	7

Table 7.25 Rock types for stone tools from Nantyreira (identifications by S. Timberlake).

Rock type	Modified hammers	Unmodified hammers	Others
Sedimentary			
Conglomerate	1	0	0
Greywacke	6	0	0
Sandstone	15	0	2
Quartzitic sandstone	1	0	0
Quartzite	1	1	0
Siltstone	3	0	0
Quartzitic siltstone	0	1	0
Igneous			
Andesite	2	0	0
Dolerite	2	0	0
Granite	2	0	0
Gabbroic	1	0	0
Pyroclastic			
Agglomerate (Borrowdale)	0	1	0
Totals	34	3	2

Table 7.26 Rock types for stone tools from Alderley Edge (identifications by Manchester Museum, G. Gaunt and after Coope *et al.* 1988).

	Pebbles originating from Triassic conglomeratic facies	Quaternary ventifacts	Glacially abraded cobbles (excluding) ventifacts	Other rounds
Number	5	4	44	33
Striated	1	2	36	-
Mean length (mm)	104	226	162	188
Visual roundness (median)	0.7	0.6	0.6	0.6
Surface smoothness (median)	6	5	3	3
Scratch hardness (median)	>6½	c. 5½	>2½ & <4	>4 & <5½
Rk (mean)	0.72	0.44	0.40	0.45
Rxs (mean)	0.54	0.23	0.27	0.34
b/a (mean)	0.74	-	0.63	0.65
c/b (mean)	0.68	0.83	0.64	0.62
c/a (mean)	0.49	-	0.44	0.42

Table 7.27 Morphological and physical properties of cobble types employed as mining tools at Alderley Edge.

1) Positions of haft modification

Modification position	Number
Transverse	64
Transverse + lateral face	15
Transverse + lateral face and edge	2
Transverse + lateral edge	1

2) Haft modification types

i) Tranverse modification*

Groove type	Number
Complete	29
Incomplete	3
Discontinuous	1
C form	5
U form	1
J form	1
Edge	6
Face	1
Damaged	29

ii) Lateral face modification

Modification type	Number
Superficial pounding	3
Notch	4
Groove types	
Complete	4
U form	1
J form	1
End	3
Edge	1
Half	1
Damaged	1

iii) Lateral edge modification

Modification type	Number
Superficial pounding	1
Notch	2
Half groove	1

* More than one groove type is present for two hammerstones

Table 7.28 Haft modification types for hammers from Alderley Edge.

	Hammers with transverse haft modification				Hammers with lateral extensions to transverse haft modification			
	Number	Median	Mean	St. dev	Number	Median	Mean	St.dev.
Visual roundness	54	0.6	-	-	16	0.6	-	-
Surface smoothness	58	3	-	-	17	4	-	-
Weight	18	1.29	-	-	8	2.25	-	-
b/a	18	-	0.62	0.08	9	-	0.63	0.14
c/b	35	-	0.63	0.17	12	-	0.70	0.18
c/a	18	-	0.43	0.08	9	-	0.43	0.10
Rk	29	-	0.42	0.22	12	-	0.46	0.18
Rxs	39	-	0.31	0.19	14	-	0.31	0.15

Table 7.29 Comparison of morphological and physical properties for modified hammers from Alderley Edge.

	Polished striae	Soft pounding	Hard pounding	Severe pounding	Flaking	Fracture
Polished striae	1.0000	- 0.0679 p = 0.284	- 0.2356 p = **0.022**	- 0.1268 p = 0.143	0.0257 p = 0.415	0.2357 p = **0.022**
Soft pounding	-	1.0000	0.2651 p = **0.012**	- 0.2055 p = **0.041**	- 0.0850 p = 0.237	- 0.1818 p = 0.062
Hard pounding	-	-	1.0000	0.2488 p = **0.017**	0.0222 p = 0.426	- 0.0875 p = 0.231
Severe pounding	-	-	-	1.0000	0.1175 p = 0.161	- 0.0576 p = 0.314
Flaking	-	-	-	-	1.0000	0.1769 p = 0.067
Fracture		-	-	-	-	1.0000

n = 73

Table 7.30 Correlation matrix for use-wear types of end-worked hammers from Alderley Edge.

	Unutilized fragments and spalls		Flake-edge tools	
	Mean	St. dev.	Mean	St.dev.
Copa Hill				
b/a	0.68	0.17	0.74	0.16
c/b	0.52	0.20	0.49	0.24
c/a	0.35	0.35	0.35	0.35
Parys Mountain				
b/a	0.75	0.12	0.74	0.14
c/b	0.53	0.22	0.54	0.22
c/a	0.39	0.16	0.39	0.15

Table 7.31 Morphological comparison of unutilized and utilized tool fragments and spalls.

	Unutilized fragments and spalls			Flake-edge tools		
	Median	Minimum	Maximum	Median	Minimum	Maximum
Copa Hill	0.59	0.02	6.40	0.57	0.10	2.00
Parys Mountain	0.26	0.02	1.68	0.50	0.20	0.98

Table 7.32 Weight data for unutilized and utilized tool fragments and spalls.

1) Great Orme

Use-wear type	First use			Second use		
	Ends	Edges	Faces	Ends	Edges	Faces
Grind marks	0	0	0	0	0	0
Striae/scratches	0	0	2	0	0	0
Polished striae	0	0	0	0	0	0
Polish	1 (0.3)	0	0	0	0	0
Bruising	0	0	3	0	0	0
Very soft pounding	15 (5.1)	2	1	0	0	1
Soft pounding	127 (43.2)	52	24	2	2	1
Hard pounding	203 (69.0)	49	37	3	3	1
Severe pounding	93 (31.6)	10	3	2	4	0
Flaking	141 (48.0)	20	2	4	1	0
Fracture flaking	66 (22.4)	6	0	4	0	0
Breakage	28 (10.5)	0	0	1	0	0
Number of artefacts	294	87	48	10	10	3

2) Copa Hill

Use-wear type	First use			Second use		
	Ends	Edges	Faces	Ends	Edges	Faces
Grind marks	0	0	0	0	0	0
Striae/scratches	3 (1.2)	2	11	0	1	5
Polished striae	0	0	0	0	0	0
Polish	0	0	0	0	0	0
Bruising	0	0	4	2	0	28
Very soft pounding	0	0	0	0	0	4
Soft pounding	30 (12.0)	1	32	20	19	40
Hard pounding	173 (68.9)	13	35	54	30	11
Severe pounding	130 (51.8)	5	6	26	8	2
Flaking	185 (73.7)	7	0	36	13	0
Fracture flaking	157 (62.5)	1	0	7	5	0
Breakage	125 (49.8)	1	0	0	0	0
Number of artefacts	251	20	48	74	43	51

3) Parys Mountain

Use-wear type	First use			Second use		
	Ends	Edges	Faces	Ends	Edges	Faces
Grind marks	0	0	0	0	0	0
Striae/scratches	1 (2.9)	0	0	0	0	0
Polished striae	0	0	0	0	0	0
Polish	0	0	0	1	1	0
Bruising	0	0	0	0	1	7
Very soft pounding	0	0	0	0	0	0
Soft pounding	10 (23.5)	3	2	5	9	7
Hard pounding	28 (79.4)	9	5	8	11	0
Severe pounding	13 (38.2)	3	0	1	3	0
Flaking	23 (67.6)	1	0	3	2	0
Fracture flaking	22 (58.8)	1	0	1	0	0
Breakage	13 (38.2)	0	0	0	0	0
Number of artefacts	34	11	5	11	14	8

Table 7.33 Frequencies of use-wear marks for mining and processing tools.

4) Nantyreira

Use-wear type	First use			Second use		
	Ends	Edges	Faces	Ends	Edges	Faces
Grind marks	0	0	0	0	0	0
Striae/scratches	0	0	1	0	0	1
Polished striae	0	0	0	0	0	0
Polish	0	0	1	0	0	1
Bruising	0	0	0	0	0	3
Very soft pounding	0	0	0	0	0	0
Soft pounding	2 (5.9)	0	0	3	0	4
Hard pounding	26 (76.5)	5	5	3	2	0
Severe pounding	20 (58.8)	0	2	3	0	0
Flaking	21 (61.8)	2	1	0	0	0
Fracture flaking	23 (67.6)	0	0	0	0	0
Breakage	13 (38.2)	0	0	0	0	0
Number of artefacts	34	5	5	4	2	5

5) Alderley Edge

Use-wear type	First use			Second use		
	Ends	Edges	Faces	Ends	Edges	Faces
Grind marks	0	0	1	0	0	0
Striae/scratches	1 (1.3)	0	0	0	0	0
Polished striae	32 (41.6)	0	0	1	0	0
Polish	4 (5.2)	1	1	0	0	0
Bruising	0	0	0	0	0	0
Very soft pounding	0	0	0	0	0	0
Soft pounding	26 (33.8)	4	4	2	0	0
Hard pounding	42 (54.5)	3	3	2	1	0
Severe pounding	12 (15.6)	2	2	1	0	0
Flaking	56 (71.4)	4	4	5	1	0
Fracture flaking	25 (32.5)	0	0	0	1	0
Breakage	16 (20.8)	0	0	0	0	0
Number of artefacts	77	8	8	6	1	0

N.B. Relative frequencies in parentheses.

Table 7.33 (Continued) Frequencies of use-wear marks for mining and processing tools.

Tool Class	Complete	Incomplete	Fragments	Cores	Totals
Copa Hill					
Hammers	10	93	92	18	213
Hammers & anvils/mortars	1	25	2	-	28
Modified hammers	-	13	5	-	18
Totals	11	131	99	18	259
Parys Mountain					
Hammers	-	10	26	-	6
Hammers & anvils/mortars	-	-	1	-	1
Modified hammers	1	2	1	-	3
Totals	**1**	**12**	**27**	-	**40**
Nantyreira					
Hammers	1	15	12	-	28
Hammers & anvils	-	1	1	-	2
Modified hammers	-	3	-	-	3
Totals	**1**	**19**	**13**	-	**33**
Great Orme					
Hammers	172	58	40	3	273
Hammers & anvils/mortars	7	9	2	-	18
Modified hammers	7	4	1	1	13
Totals	**189**	**71**	**48**	**4**	**312**
Alderley Edge					
Hammers	2	3	1	-	6
Modified hammers	27	45	8	-	80
Modified hammers & anvils	-	1	-	-	1
Totals	**29**	**49**	**9**	-	**87**

Table 7.34 Tool classes of mining tools by site assemblage.

	Unmodified hammers	Modified hammers	Possible modified hammers
Great Orme			
Flat-ended	2	0	0
Edge-shaped ends	6	0	0
Pointed ends	1	1	0
Number of artefacts	279	14	14
Copa Hill			
Flat-ended	5	1	0
Edge-shaped ends	1	0	0
Pointed ends	0	0	0
Number of artefacts	240	18	21
Parys Mountain			
Flat-ended	0	0	0
Edge-shaped ends	0	0	0
Pointed ends	0	0	0
Number of artefacts	37	3	11
Nantyreira			
Flat-ended	0	0	0
Edge-shaped ends	0	0	0
Pointed ends	0	0	0
Number of artefacts	30	3	4
Alderley Edge			
Flat-ended	0	2	-
Edge-shaped ends	0	6	-
Pointed ends	0	5	-
Number of artefacts	6	79	0

Table 7.35 Unsuitable shapes of cobble ends used as hammers.

		Great Orme		Copa Hill		Parys Mountain		Nantyreira		Alderley Edge	
		Primary	Secondary	Primary	Secondary	Primary	Secondary	Primary	Secondary	Primary	Secondary
	0	12	-	16	4	2	-	3	-	21	2
Haft	1	2	-	1	0	0	-	0	-	22	4
Polish	2	0	-	1	0	1	-	0	-	13	1
	3	0	-	0	0	0	-	0	-	6	1
	4	0	-	0	0	0	-	0	-	9	0
	5	0	-	0	0	0	-	0	-	6	1

Table 7.36 Frequency of haft polish for transversely modified hammers.

Assemblage	Primary			Secondary		
	Superficial pounding	Notch	Groove	Superficial pounding	Notch	Groove
Great Orme	7	6	1	-	-	-
Copa Hill	11	4	3	0	4	0
Parys Mountain	1	1	1	-	-	-
Nantyreira	2	1	0	-	-	-
Alderley Edge	2	5	75	0	5	4

Table 7.37 Frequencies of haft modification types.

	Primary				Secondary			
	Number	Median	Minimum	Maximum	Number	Median	Minimum	Maximum
Great Orme	13	1.5	0.0	12.0	-	-	-	-
Copa Hill	18	2.0	0.0	4.0	4	6.00	5.0	8.0
Parys Mountain	3	-	0.0	3.0	-	-	-	-
Nantyreira	3	-	0.0	4.0	-	-	-	-
Alderley Edge	77	8.5	0.0	21.0	8	8.25	0.0	19.0

Table 7.38 Depth of haft modification (mm). Statistics based on the maximum depth of modification for the individual hammers.

	Mount Gabriel	Great Orme	Copa Hill	Parys Mountain	Nantyreira	Alderley Edge
Sample Size	561	331	268	41	37	88
Haft modification	40%	4-8%	7-15%	7-34%	8-19%	91%
One end used	43%	12%	12%	10%	12%	19%
Both ends used	52%	55%	51%	41%	41%	55%
Serviceable cobbles	40%	70%	33%	17%	32%	66%
Unused cobbles	2%	10%	0.4%	-	5%	2%
Premature fracture	11%	3%	5%	7%	5%	3%

Table 7.39 Comparison of use forms with the Mount Gabriel study (after O'Brien 1994, 132).

Plate 2. A large stone hammer from the Great Orme Copper Mines (GOR 138). It has a line of pound marks on its face which may be related to haft modification.

CHAPTER EIGHT

The Form of Mining Tools in Relation to Cobble Sources

8.1 Introduction

In order to investigate the properties sought for in the selection of cobbles for use as mining tools, probable sources for the mine sites with large stone tool assemblages (Copa Hill and Great Ormes Head) have been studied. This chapter presents the selection and description of sampling sites, along with sampling methods, and a summary of their cobble morphology. This shape and roundness data are then compared with mining tools.

8.2 Method

The following parameters are recorded for cobbles falling into the same size range as the stone tools, as set out in sections 5.2 and 5.3:

1) weight.

2) the three axial dimensions.

3) visual roundness.

4) the diameter of the sharpest corner in the plane of maximum projection, denoted as 'Dk'.

5) the diameter of the sharpest corner in cross-section, denoted as 'Dxs' .

6) the shape of the cobble's faces .

7) the presence of glacial abrasion marks and fracture .

8) surface conditions which would have limited the choice of stones, such as the presence of barnacles and seaweed, depending on their position on the beach.

The five shape indices are used to analyse cobble shape as described in section 7.1.1. The primary data is presented in Appendix One.

8.3 Great Ormes Head

8.3.1 Description

As the majority of stone tools were probably derived from beach shingle, the study site is located at the beach at Bishop's Palace, Gogarth Bay (SH 760829). This area was selected as it had escaped disturbance from the construction of modern sea defences, piers, roads and buildings. It is a low energy beach which is sheltered from storms except those coming from the north-west. The foreshore consists of a shingle upper beach with a relatively steep beach face, and a low tide terrace of sand (fig 8.1). The backshore is narrow and consists of shingle and limestone boulders. The beach sediment is derived from North Welsh and Irish Sea tills which form a cliff of drift about 10m in height. This is overlain by a thin discontinuous ribbon of glacial sands and gravels whose extent is limited to the shore side of the boulder clay. (The full extent of this cannot be shown at the scale used in figure 7.4). The till sequence consists of a dark blue-grey clay, Welsh boulder clay, which contains numerous pebbles and boulders. This is overlaid by the Irish Sea till, a stiff red clay capped by sand and relatively stone free. The boundary between the two tills is well defined although in places they are separated by poorly sorted coarse gravels (plate 3).

8.3.2 Sampling

Survey 1. Rock types

The rock type composition of the shingle foreshore has been assessed by counts in two transects across the upper beach. This is achieved by counting and weighing rocks in the same size range of 70 to 400mm in length from 50cm squares at 2½m intervals. The following classes of rock types are used: 1) limestone, 2) sandstone/grit, 3) mudstone/siltstone, 4) pyroclastics and rhyolite, 5) granite, 6) basalt and dolerite, 7) gabbro,

Plate 3. Section of the North Welsh and Irish Sea tills exposed in section at Bishop's Palace, Gogarth Bay, on the Great Ormes Headland.

and 8) microdiorite. Pebbles straddling the edges of the sample area have only been included if 50 percent or more of their surface was contained within the sample square.

Survey 2. Cobble form

A series of samples have been taken across the upper beach profile (fig. 8.1) in order to take account of any sorting of the beach sediment by size and shape. The position of the samples are as follows:

1) the high tide mark - sample 1.

2) the plunge step - sample 2.

3) the backshore - sample 3.

The sampling method involved taking all surface material, in the same size range as above, from one square metre. Shape and size analysis by rock type is not considered appropriate because the stone tool assemblage is comprised of many small rock type groups. The results of the first survey, below, show that most of these rock types are relatively uncommon on the beach which would have meant that it would have been a very time consuming exercise if sufficient sample sizes were to be procured.

8.3.3 Results

Survey 1

The results of the survey of the shingle composition for the upper shore are given in table 8.1. The beach material is dominated by limestone and, to a much lesser extent, other sedimentary rocks, constituting over two-thirds by number or around 80 percent by weight. Other uncommon rocks not falling into the type categories included chert and quartz. Since exotic rock types are all smaller in size than the locally derived limestone, frequencies based on weight rather than counts are a better measure of rock type abundances. It suggests that the larger sized exotic cobbles used as stone tools are particularly scarce.

Survey 2

The presence of barnacles (10%) and seaweed (8%) has been recorded for the stones in the lower edge of the shingle beach. As barnacles only occurred in small numbers, their presence would not have affected the selection of stones from this position. Few stones below the plunge step would have been suitable material for stone tools because of the effects of seaweed. Rather surprisingly, only one example of a glacially abraded cobble has been recorded, although a notable proportion of the backshore sample is broken.

Samples 1 and 3 contain a greater proportion of small cobbles (see fig 8.2). The most likely explanation for this concentration at the top of the beach is that they were thrown there during storm conditions. There is no evidence to suggest sorting by shape (see table 8.2). The sample means for the shape and roundness variables are compared using Hotelling's T^2 statistic (table 8.3). The observed significance levels for the backshore sample compared to the foreshore samples are both very small. The univariate F-tests for the individual variables show that the axial ratios are insignificant, whereas the roundness indices are highly significant. In conclusion, the cobbles from the backshore are equal in shape but more angular than those from the foreshore. This result simply reflects differences in abrasion between littoral and fluvioglacial environments.

8.3.4 Comparison with mining tools

An initial idea of the degree of selectivity in the shape of cobbles for use as stone tools is achieved by comparing the scatter plots of axial dimensions for worked stone and beach cobbles (fig. 8.3). The 'breadth' versus 'depth' axes plot for stone tools suggests that the relationship is not strictly linear, and that shape changes with size. Overall, the hammers show a tighter distribution (lower variance) than the beach cobbles, particularly the smaller ones.

Detailed morphological comparison of beach cobbles to mining tools is made difficult due to differences in roundness between positions on the shore and, in the case of stone tools, differences in shape and roundness between size groups and cobble types. In general, stone tools are much more rounded than beach cobbles (fig. 8.4) and display a greater proportion of more highly abraded shape forms (table 8.4). The mean axial ratios suggest that stone tools are also more compact in shape. As the variation in axial shape between samples taken from the beach is not significant, a statistical comparison with mining tools can be made. The multivariate test shows that overall difference in shape is not significant but the univariate F-test for the ratio c/a alone is significant (table 8.5).

8.4 Cwmystwyth

8.4.1 Description

The most convenient source of cobbles would have been the River Ystwyth. This is a coarse bed load stream comprised of local Silurian shales and grits derived from valley alluvium, morainic drift, and solifluction and nivation deposits (Brown 1952; Watson 1968). Valley-side tributaries on the south-facing side of the Ystwyth, such as Nant yr Onen, and hillside drift exposures, are other possible sources. Although these occur closer to the mine site they would have been poor sources as they contain stones derived from head and scree which have undergone a relatively low degree of abrasion.

8.4.2 Sampling

Sampling sites have been carefully located to avoid disturbance from industrial mining (fig. 8.5). As a number of stone hammers from Copa Hill show evidence of glacial abrasion, a sample derived from a solifluction/nivation deposit has been included. Although these deposits contain glacial material, i.e. glacially abraded stones, their terraced form suggests that they were formed by slope processes (Watson 1970).

The following sites have been sampled:

1) hillslope wash derived from a solifluction/nivation deposit below Lanfawr (SN 833 764) - sample 1.

2) stream bed of valley-side tributary adjacent to 2) - sample 2.

3) stream bed of the River Ystwyth below Copa Hill (SN 812748) - sample 3.

In each case a grab sample of cobbles in the size range of 80 to 375mm in length has been taken. A more refined method of sampling was not possible as the River Ystwyth was in flood. The rock types of the cobbles were classified into three groups on the basis of grain size, i.e. coarse-grained (coarse-grained sandstone), medium-grained (sandstone), and fine-grained (shales).

8.4.3 Results

The shape and roundness data by rock type for the three samples are presented in table 8.6. Apart from the overall increase in roundness with fluvial abrasion, there are other trends which are apparent:

1) The degree of roundness is related to grain size; coarse-grained rocks being the most rounded.

2) Cobble size is related to grain size; fine-grained rocks (shales) being the smallest.

3) Fine-grained rocks are more oblate whereas medium and coarse-grained rocks are more prolate.

As fine-grained rocks were not employed as mining tools, rocks of this type are excluded from further analysis. Tests for differences in form variables between medium and coarse-grained rocks show that significant differences in roundness exist for the two samples taken at Lanfawr but not for those from the River Ystwyth (table 8.7).

The frequencies of occurrence of both glacial surface forms and natural breakages by rock type are given in table 8.8. Sample 2 illustrates the fact that glacial striae are erased more quickly from finer-grained, less durable, rocks. Snub scars are relatively uncommon. No examples of glacially abraded cobbles have been observed for the River Ystwyth sample.

Metrical data for the cobble morphology of stone tools from Copa Hill is limited, due to the high degree of use-breakage. As a result, the comparison of shape variables with cobble sources is only possible for roundness measurements. Comparison of visual roundness with facial shape components (fig. 8.6 and table 8.9) suggests that the valley-sides and stream tributaries, such as those studied at Lanfawr, would have yielded very few stones suitable for use as stone tools, and that the river bed of the River Ystwyth would have been the most suitable source. Even so, 36 percent of the stone tool assemblage have visual roundness values above those recorded for the Ystwyth sample. Comparison of shape forms for mining tools and river cobbles (excluding fine-grained rocks) shows that the mining tools display a greater proportion of abraded shape forms (table 8.10). It is also possible to compare the means (student t-test) and variances (F-test) for the two roundness indices show that there are very significant differences, river cobbles being more angular than stone tools (table 8.11).

It is possible that the river gravel sample may be slightly biased towards less rounded cobbles because it was taken from the margins of the river bed where the discharge is low. Unfortunately, due to the high level of the river, it was not possible to sample more wandering gravel at the time. Another possible factor, which should be considered, is that there may have been changes in sediment input since the Bronze Age as the result of factors such as deforestation.

8.5 Conclusion

Both studies indicated that well-rounded cobbles were preferentially selected for use as stone tools for mining. In fact, over one-third of the Copa Hill assemblage fell into roundness categories above those recorded for cobbles taken from the most suitable source. Comparison of cobble shape by using axial ratios is only possible for the Great Orme material. The only significant difference is found, univariately, for the c/a ratio and it is possible that this is related to roundness.

The high degree of roundness displayed by the Great Orme mining tools, which show low use-breakage and consumption, suggests that well-rounded cobbles were not selected entirely for their improved mechanical strength but for other factors, such as ease of handling. The effect of the degree of roundness on the effectiveness of hafting/handling is an area which requires further investigation since a more rounded cross-section would provide a greater contact area for the hand or haft to grip.

More detailed analysis of the morphological properties involved in the selection of cobbles for mining at the two sites is limited, due to their individual circumstances. Although the mine tooling at Copa Hill is more straightforward, the difficulty is in obtaining sufficient numbers of relatively complete stone hammers in order to carry out comparisons with sediment sources. The situation for Great Orme is much more complex as there appears to be a number of hammer sizes with many more rock types having been used. The relationship between rock types and cobble morphology requires detailed examination and further samples of stone tools need to be studied in order to verify the size groups and the morphological differences between them. Only then can they be properly compared with sediment sources.

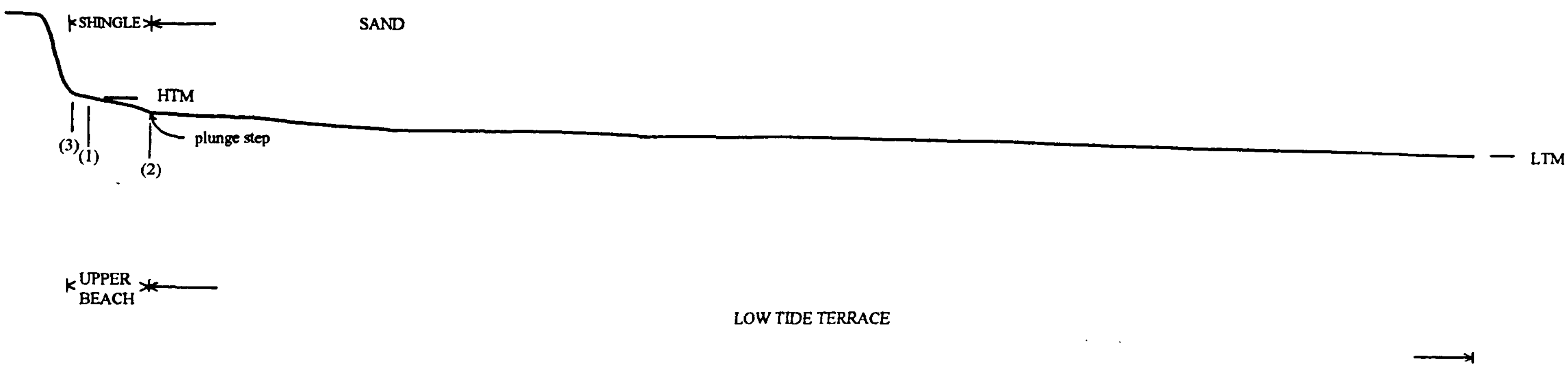


Figure 8.1 Beach profile (NE facing) at Bishop's Palace, Gogarth Bay, showing the position of the cobble samples taken for Survey 2. Horizontal scale 1:2000. Vertical scale 1:1000. Key: HTM - high tide mark, WTM - low tide mark.

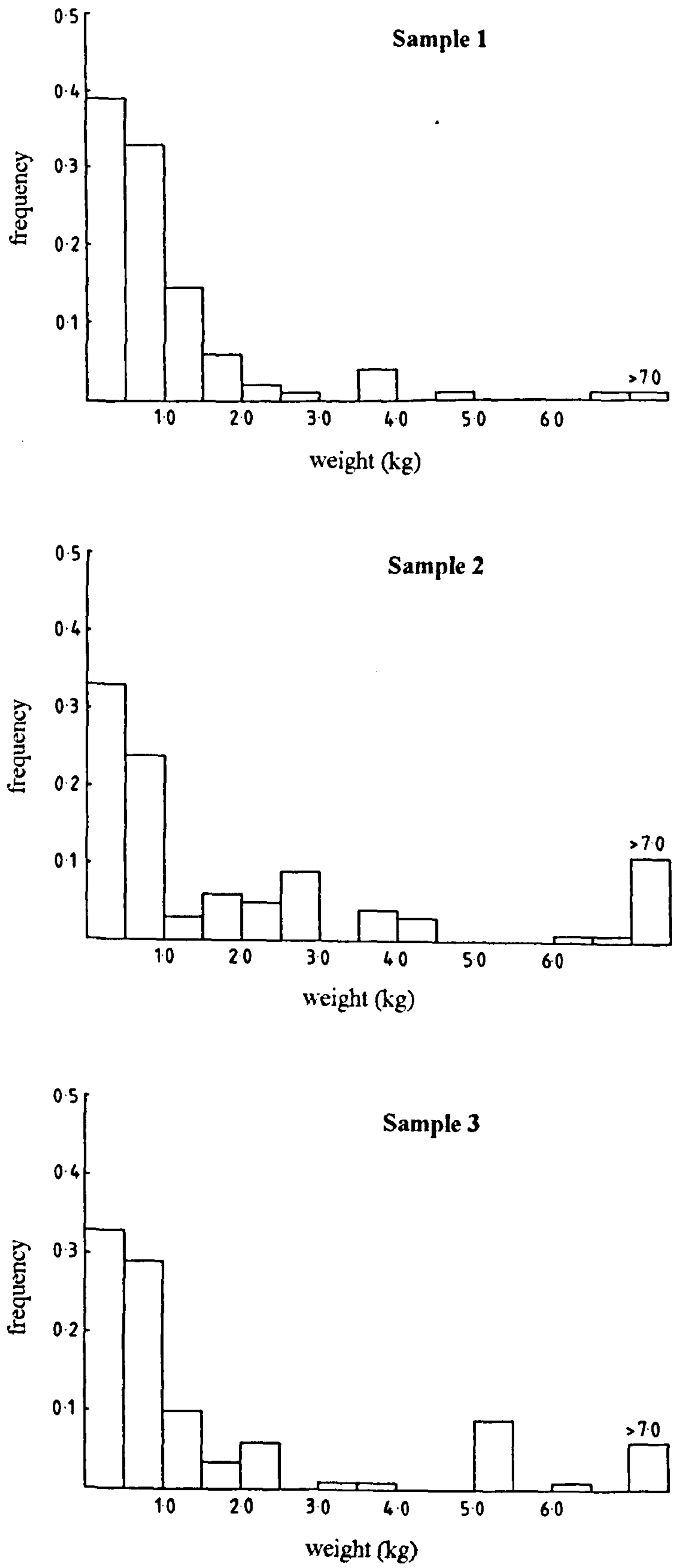


Figure 8.2 Relative frequency histograms of cobble weights for beach cobbles taken at Gogarth Bay, the Great Ormes Head.

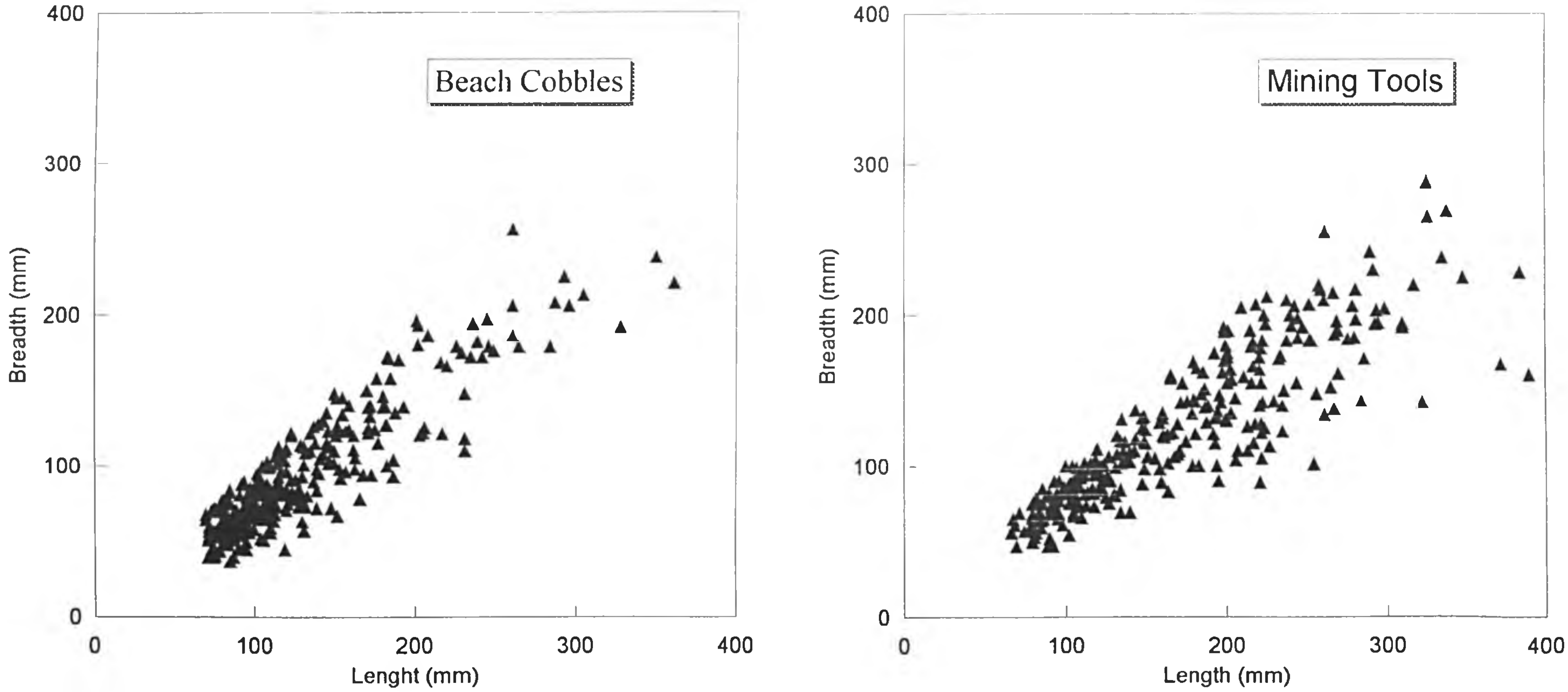


Figure 8.3 Scatter plots comparing the axial dimensions of beach cobbles sampled from Gogarth Bay and mining tools from the Great Orme Mines.

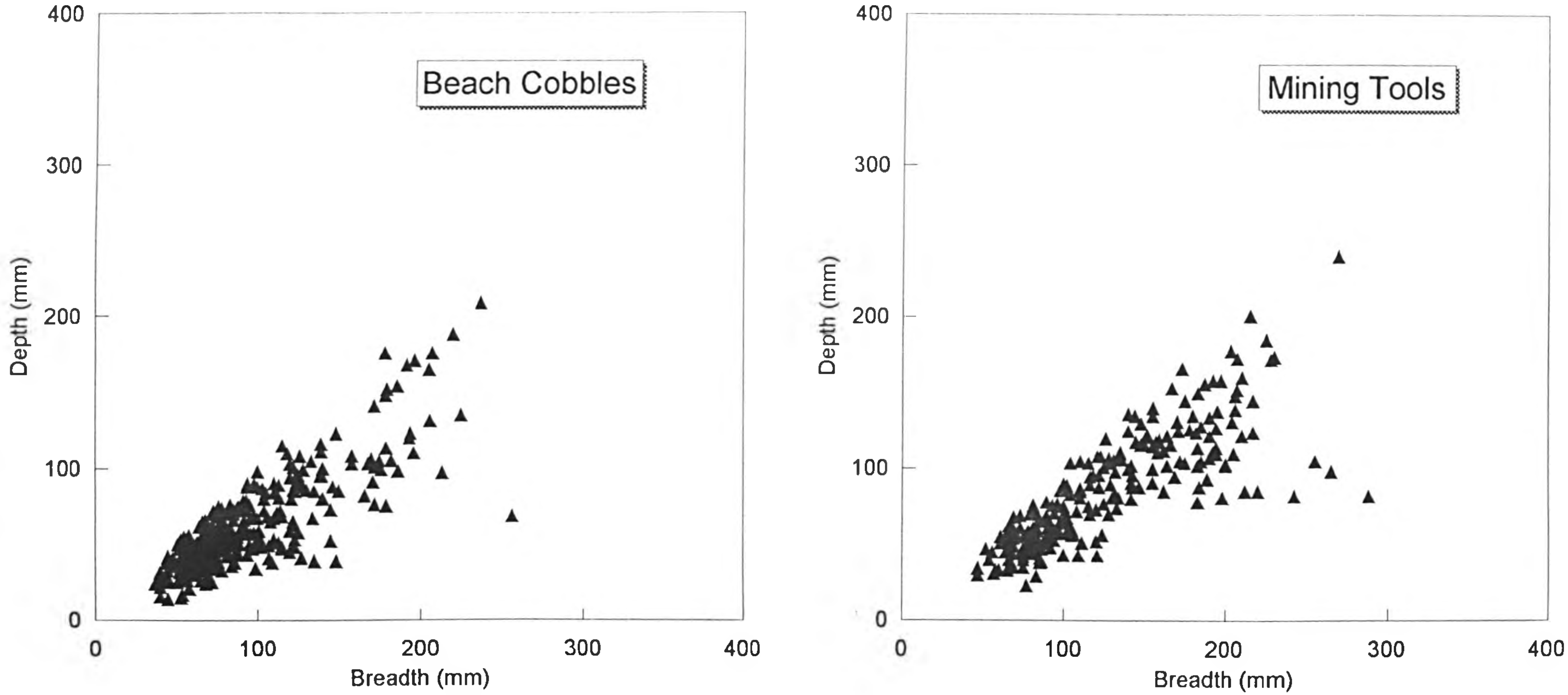


Figure 8.3 (continued) Scatter plots comparing the axial dimensions of beach cobbles sampled from Gogarth Bay and mining tools from the Great Orme Mines.

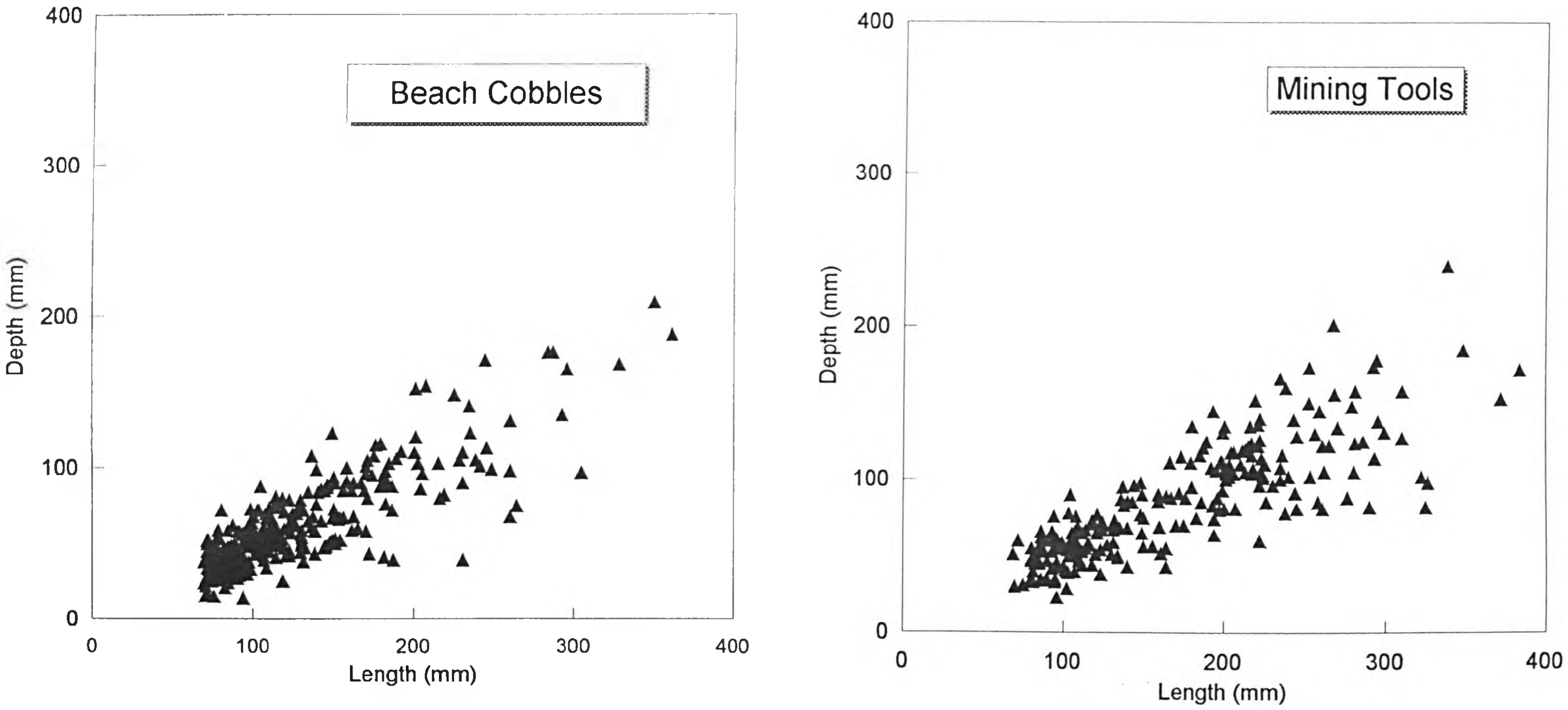


Figure 8.3 (continued) Scatter plots comparing the axial dimensions of beach cobbles sampled from Gogarth Bay and mining tools from the Great Orme Mines.

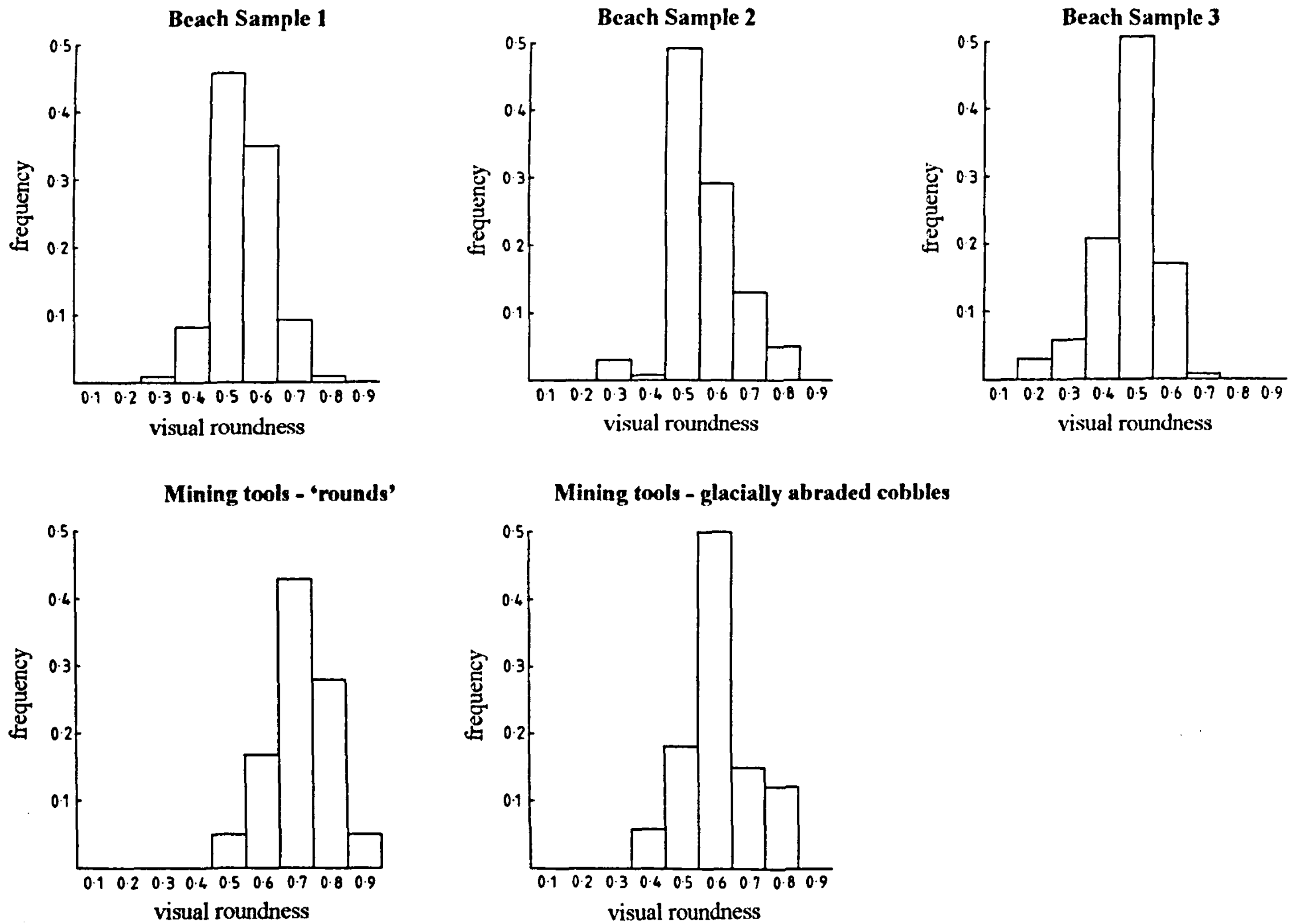


Figure 8.4 Relative frequency histograms of cobble roundness for beach cobbles and mining tools, the GreatOrmes Head.

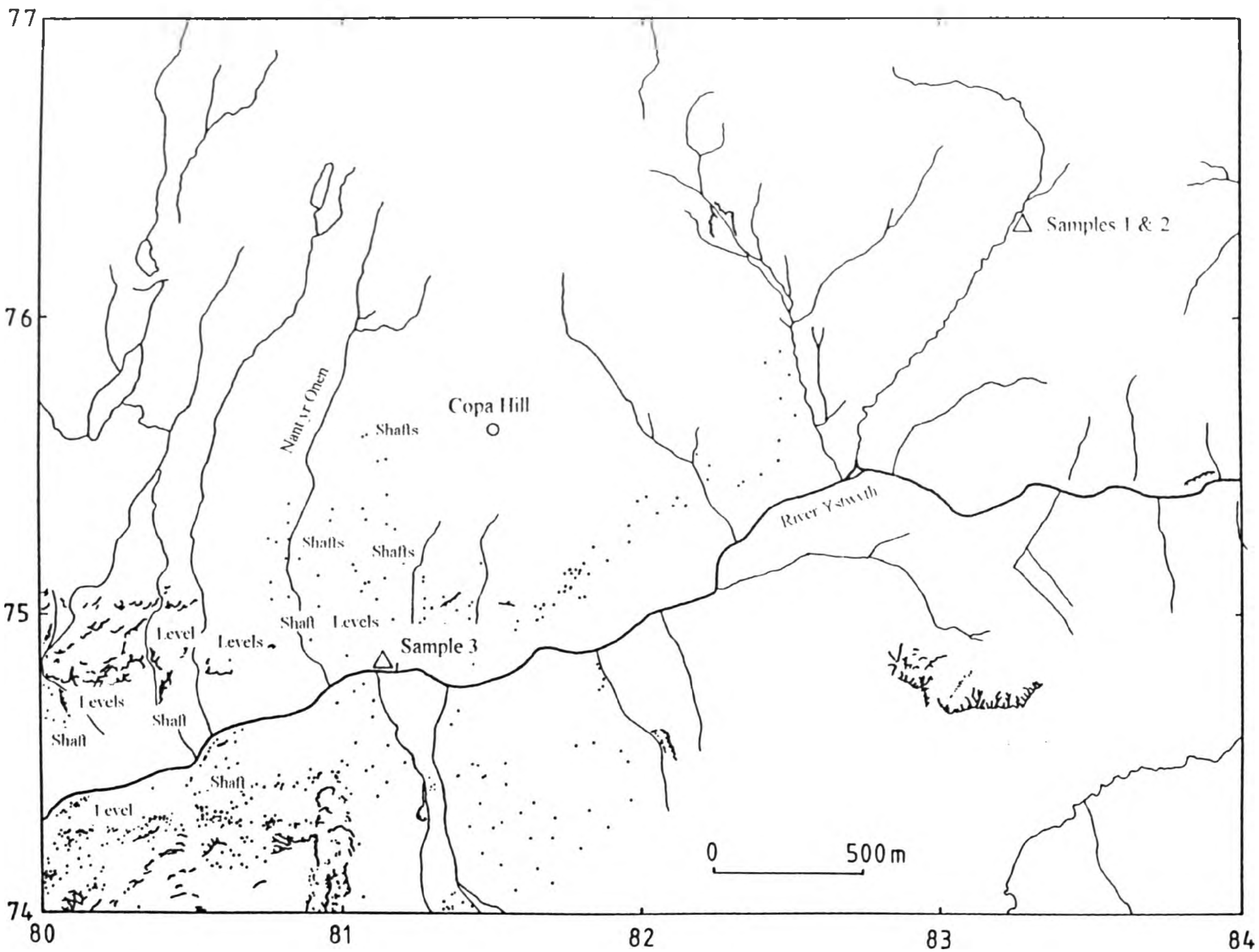


Figure 8.5 Location map of the samples taken in the Cwmystwyth cobble survey.

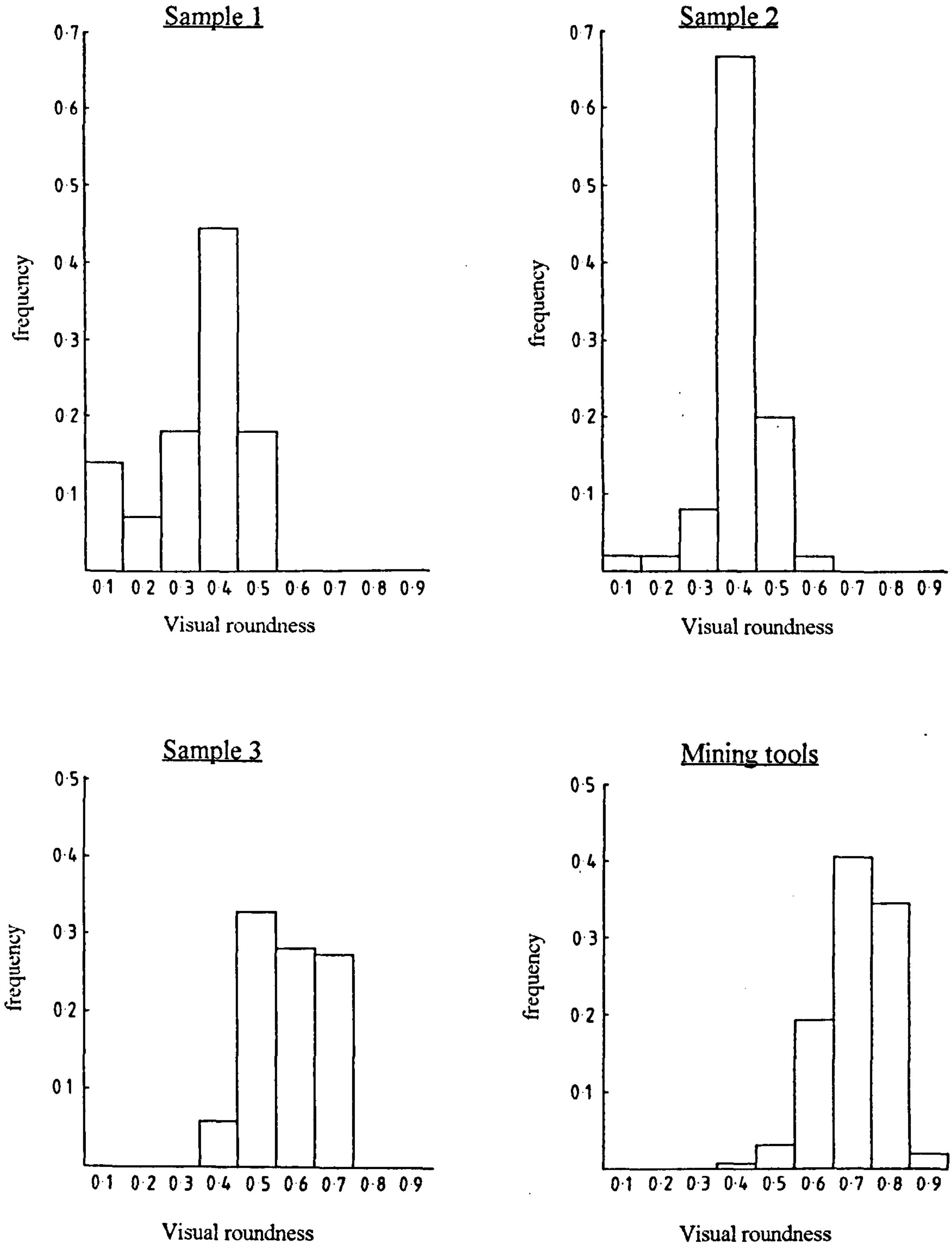


Figure 8.6 Relative frequency histograms of cobble roundness for sediment samples and mining tools, Cwmystwyth.

Sample number	Limestone	Sandstone and grits	Mudstone/ siltstone	Pyroclastics & rhyolite	Granite	Basalt & dolerite	Gabbro	Microdiorite	Others	Unidentified	Totals
Transect 1											
1	18 (5.5)	4 (0.35)	2 (0.2)	2 (0.6)	-	2 (0.5)	1 (0.2)	4 (0.85)	3 (0.25)	-	36 (8.45)
2	12 (6.3)	-	2 (0.8)	3 (0.23)	1 (0.1)	3 (1.5)	-	3 (3.0)	1 (0.2)	5 (1.9)	30 (16.1)
3	5 (8.5)	1 (3.6)	2 (4.5)	4 (5.9)	1 (2.55)	1 (0.35)	-	-			14 (25.4)
4	10 (23.0)	2 (7.6)	2 (3.0)	-	-	-	-	-	-	1 (0.2)	15 (33.8)
5	6 (32.5)	1 (1.5)	1 (0.7)	-	-	-	-	-	-	1 (0.2)	9 (34.9)
6	6 (28.6)	1 (0.25)	-	-	-	1 (0.25)	2 (2.25)	-	-	-	10 (31.35)
7	3 (1.3)	-	1 (0.9)	-	-	-	-	3 (6.9)	-	-	7 (9.1)
8	5 (26.0)	-	1 (6.8)	3 (7.1)	-	-	-	-	-	-	9 (39.9)
Transect 2											
1	-	1 (0.2)	-	-	-	-	-	-	-	-	1 (0.2)
2	3 (3.8)	1 (0.4)	2 (3.4)	2 (1.3)	-	-	-	-	-	1 (0.6)	9 (9.5)
3	8 (9.5)	1 (0.4)	-	-	-	-	-	-	-	2 (0.6)	11 (10.5)
4	3 (15.0)	-	-	1 (0.65)	-	-	-	-	-	-	4 (15.65)
5	4 (4.0)	-	1 (0.2)	1 (0.1)	-	-	-	2 (2.35)	-	-	8 (6.65)
6	4 (4.5)	1 (0.75)	1 (1.5)	-	-	-	-	-	-	1 (2.3)	7 (9.05)
7	10 (16.0)	2 (2.2)	4 (4.8)	1 (0.3)	1 (2.1)	-	-	-	-	3 (9.0)	21 (34.4)
11	10 (7.3)	2 (0.4)	1 (0.5)	1 (0.6)	-	1 (0.3)	-	-	1 (0.85)	1 (0.85)	17 (10.8)
Totals	107 (191.8)	17 (17.65)	20 (27.3)	18 (18.85)	3 (4.75)	8 (2.9)	3 (2.45)	12 (13.1)	5 (1.3)	15 (15.65)	208 (295.75)
Number frequency	51.44	8.17	9.62	8.65	1.44	3.85	1.44	5.77	2.40	7.21	-
Weight frequency	65.04	5.99	9.26	6.39	1.61	0.98	0.83	4.44	0.44	5.02	-
Mean weight	1.79	1.04	1.37	1.05	1.58	0.36	0.82	1.09	0.26	0.99	-

NB Weights given in parentheses

Table 8.1 Shingle composition at Gogarth Bay, the Great Ormes Head.

1. Beach cobble survey, Bishop's Palace, Gogarth Bay.

	Sample 1		Sample 2		Sample 3	
	Mean	St. dev.	Mean	St. dev.	Mean	St.dev.
b/a	0.73	0.14	0.74	0.13	0.75	0.13
c/b	0.69	0.18	0.65	0.15	0.68	0.17
c/a	0.49	0.13	0.47	0.12	0.50	0.11
Rk	0.38	0.15	0.37	0.17	0.24	0.15
Rxs	0.30	0.14	0.31	0.16	0.18	0.12
	Median		Median		Median	
Visual roundness	0.5		0.5		0.5	
Weight	0.6		0.9		0.7	
Number	142		79		70	

2. Mining tools.

	Glacially abraded cobbles			Other rounds		
	Number	Mean	St. dev.	Number	Mean	St.dev.
b/a	29	0.74	0.12	209	0.76	0.12
c/b	30	0.69	0.13	229	0.69	0.15
c/a	28	0.51	0.12	203	0.52	0.12
Rk	31	0.51	0.28	248	0.69	0.20
Rxs	31	0.37	0.12	252	0.54	0.18
		Median			Median	
Visual roundness	34	0.6		330	0.7	
Weight	30	2.55		220	3.25	

Table 8.2 Summary of shape and size data for beach cobble study and mining tools, the Great Ormes Head.

Samples 1 and 2

Test name	T^2 statistic	F statistic	Degrees of freedom	Significance of F
Hotellings T^2 test	0.0153	0.6570	215	0.656

Univariate F-tests with (1, 219) degrees of freedom

Variable	F statistic	Significance of F
b/a	0.2177	0.641
c/b	2.0489	0.154
c/a	0.7753	0.380
Rk	0.0192	0.890
Rxs	0.7665	0.382

Samples 1 and 3

Test name	T^2 statistic	F statistic	Degrees of freedom	Significance of F
Hotellings T^2 test	0.2061	5.8120	564	0.0005

Univariate F-tests with (1, 287) degrees of freedom

Variable	F statistic	Significance of F
b/a	0.4603	0.632
c/b	1.1664	0.313
c/a	0.8953	0.410
Rk	19.9629	0.000
Rxs	20.8849	0.000

Sample 2 and 3

Test name	T^2 statistic	F statistic	Degrees of freedom	Significance of F
Hotellings T^2 test	0.2531	7.1866	142	0.0005

Univariate F-tests with (1, 146) degrees of freedom

Variable	F statistic	Significance of F
b/a	0.2020	0.654
c/b	1.7108	0.193
c/a	1.9411	0.166
Rk	25.8782	<0.001
Rxs	32.3739	<0.001

Table 8.3 Comparison of variation in shape for cobble samples taken on the shore of Gogarth Bay, the Great Ormes Head.

Chi-Square Test for Independence

Ho: The selection of cobbles for use as mining tools does not depend on shape.
H_1: The selection of cobbles for use as mining tools is related to shape.

	Convex	Flat	Concave	Totals
Beach cobbles	30 (104.15)	135 (108.62)	126 (78.23)	291
Mining tools	203 (128.85)	108 (134.38)	49 (96.77)	360
Totals	175	243	175	651

Expected frequencies in parenthesis.

$X^2 = 159.813$ (2 degrees of freedom)
$X^2(0.001) = 13.816$

Conclusion. Observed value of X^2 is in the critical region, therefore, we reject Ho.

Table 8.4 Comparison of shape forms for beach cobbles and mining tools from the Great Ormes Head.

Test name	T^2 statistic	F statistic	Degrees of freedom	Significance of F
Hotellings T^2 test	0.0114	1.9418	509	0.122

Univariate F-tests with (1, 511) degrees of freedom

Variable	F statistic	Significance of F
b/a	2.7439	0.098
c/b	0.7011	0.403
c/a	4.7064	0.031

Table 8.5 Comparison of variation in shape for beach cobbles and mining tools, the Great Ormes Head.

Sample 1. Hillslope wash, Lanfawr.

	Fine-grained		Medium-grained		Coarse-grained	
	Mean	St. dev	Mean	St.dev	Mean	St.dev
b/a	0.65	0.13	0.67	0.22	0.64	0.12
c/b	0.51	0.16	0.56	0.18	0.61	0.17
c/a	0.32	0.10	0.38	0.18	0.38	0.11
Rk	0.07	0.04	0.07	0.03	0.10	0.06
Rxs	0.07	0.07	0.05	0.05	0.10	0.09
	Median		Median		Median	
Visual roundness	0.30		0.35		0.40	
Weight	0.45		0.60		0.80	

Sample 2. Stream gravel, valley-side tributary, Lanfawr.

	Fine-grained		Medium-grained		Coarse-grained	
	Mean	St. dev	Mean	St.dev	Mean	St.dev
b/a	0.78	0.16	0.70	0.16	0.71	0.14
c/b	0.40	0.11	0.53	0.16	0.56	0.16
c/a	0.32	0.12	0.37	0.14	0.39	0.11
Rk	0.08	0.04	0.16	0.09	0.21	0.11
Rxs	0.08	0.04	0.11	0.10	0.19	0.07
	Median		Median		Median	
Visual roundness	0.30		0.40		0.40	
Weight	0.80		1.03		1.10	

Sample 3. Stream gravel, River Ystwyth, Cwmystwyth.

	Fine-grained		Medium-grained		Coarse-grained	
	Mean	St. dev	Mean	St.dev	Mean	St.dev
b/a	0.73	0.18	0.68	0.16	0.68	0.15
c/b	0.49	0.17	0.58	0.19	0.54	0.19
c/a	0.34	0.12	0.38	0.14	0.36	0.14
Rk	0.21	0.11	0.39	0.18	0.49	0.20
Rxs	0.19	0.10	0.30	0.17	0.33	0.10
	Median		Median		Median	
Visual roundness	0.50		0.50		0.60	
Weight	0.95		1.65		1.80	

Table 8.6 Summary of shape and size data for Cwmystwyth cobble survey.

Sample 1. Hillslope wash, Lanfawr.

Test name	T^2 statistic	F statistic	Degrees of freedom	Significance of F
Hotellings T^2 test	0.1464	1.4934	51	0.208

Univariate F-tests with (1, 55) degrees of freedom		
Variable	F statistic	Significance of F
b/a	0.3351	0.565
c/b	0.9856	0.325
c/a	0.0502	0.824
Rk	5.7240	0.020
Rxs	5.7203	0.020

Sample2. Stream gravel, valley-side tributary, Lanfawr.

Test name	T^2 statistic	F statistic	Degrees of freedom	Significance of F
Hotellings T^2 test	0.2962	2.6656	45	0.034

Univariate F-tests with (1, 49) degrees of freedom		
Variable	F statistic	Significance of F
b/a	0.1229	0.727
c/b	0.7223	0.400
c/a	0.4708	0.496
Rk	3.0937	0.085
Rxs	9.6300	0.003

Sample 3. Stream gravel, River Ystwyth, Cwmystwyth.

Test name	T^2 statistic	F statistic	Degrees of freedom	Significance of F
Hotellings T^2 test	0.0700	1.1615	83	0.335

Univariate F-tests with (1, 87) degrees of freedom		
Variable	F statistic	Significance of F
b/a	0.0000	0.971
c/b	0.0207	0.447
c/a	0.0102	0.460
Rk	0.1485	0.054
Rxs	0.0191	0.375

Table 8.7 Comparison of variation in shape for medium- and coarse-grained rocks, Cwmystwyth cobble survey.

Rock type	Number	Marks of glacial abrasion					Breakage
		Striae Intensity			Striae & snub scars	Snub scars	
		Faint	Clear	Marked			
Sample 1.							
Fine-grained	63	18	10	5	2	1	3
Medium-grained	26	9	6	2	1	-	5
Coarse-grained	31	8	6	4	3	3	4
Sample 2.							
Fine-grained	13	-	-	-	-	-	-
Medium-grained	22	3	4	-	-	-	1
Coarse-grained	29	4	10	2	-	-	-
Sample 3.							
Fine-grained	14	-	-	-	-	-	-
Medium-grained	20	-	-	-	-	-	3
Coarse-grained	69	-	-	-	-	-	1
Copa Hill.							
Mining tools	376	20	9	-	-	2	2

Table 8.8 Cobble surface textures for sediments and mining tools, Cwmystwyth.

Shape forms	Sample 1	Sample 2	Sample 3	Copa Hill
Convex	0	0	19	99
Flat	27	28	43	115
Concave	30	23	27	24
Totals	57	51	89	238

Table 8.9 Cobble shape forms for medium- and coarse-grained rocks of sampled sediments and mining tools, Cwmystwyth.

Chi-Square Test for Independence

Ho: The selection of cobbles for use as mining tools does not depend on shape.
H_1: The selection of cobbles for use as mining tools is related to shape.

	Convex	Flat	Concave	Totals
Copa Hill	99 (85.88)	115 (115.00)	24 (37.12)	238
Sample 3	19 (32.12)	43 (43.00)	27 (13.88)	89
Totals	118	158	51	327

Expected frequencies in parentheses.

$X^2 = 24.396$ (2 degrees of freedom)
$X^2(0.001) = 13.816$

Conclusion. Observed value of X^2 is in the critical region, therefore, we reject Ho.

Table 8.10 Comparison of shape forms for mining tools, Copa Hill, and medium- and coarse-grained stream cobbles from the River Ystwyth.

Kuenen's Roundness Formula, Rk

Sample	Number	Sample mean	Sample st. dev.
Mining tools	62	0.617	0.197
Stream cobbles	89	0.463	0.201

Two (independent) sample t-test (one-tailed)
t= 4.69 with 132 degrees of freedom. $p = < 0.0001$

F-test
F = 1.041 with (88, 61) degrees of freedom. F(0.05) = 1.53

Cross-sectional Roundness Formula, Rxs

Sample	Number	Sample mean	Sample st. dev.
Mining tools	47	0.493	0.205
Stream cobbles	89	0.324	0.155

Two (independent) sample t-test (one-tailed)
t= 4.97 with 74 degrees of freedom. $p = < 0.0001$

F-test
F = 1.749 with (46, 88) degrees of freedom. F(0.05) = 1.59

Table 8.11 Comparison of cobble roundness for mining tools, Copa Hill, and medium- and coarse-grained stream cobbles from the River Ystwyth.

CHAPTER NINE

Discussion

9.1 Characterization of Bronze Age metal mining practices

The analysis of cobble morphology and use-wear has identified evidence of stone hammer specialization for the two mines with soft mineral deposits, ie the Great Orme and Alderley Edge (sections 7.2.2.1 and 7.6.2.3). At the Great Orme, these tool types have been linked to differences in the form of mine workings and extractive conditions resulting from the variable geological structure of the mineral deposit (section 7.9). For the harder deposits, where the mineralization is contained within quartz veins, there is some limited evidence at Copa Hill to suggest that hammer size may be linked to the size of the workings (section 7.3.2.1), however, this requires further investigation. As insufficient numbers of undamaged tools have been recovered for three of the assemblages for these to be studied in full detail, the results of this thesis cannot be applied to other sites. It would seem likely, however, that these harder mineral deposits will in general lack diversity in hammer size and use regardless of the forms of working because of the relative homogeneous structure of these mineral deposits. Present data suggests were they most effectively tackled by hand held/hafted mauls.

The study has also shown that it is possible to identify other tool materials used in conjunction with stone hammers by examining use-wear. It is suggested that bone/wood points were employed at the Great Orme and that metal tools may also have been used at other sites (section 7.9). This needs to be confirmed by replicative analysis of stone hammer use-wear.

The comparison of stone tool consumption for the mine sites can be achieved by studying use patterns, haft modification and cobble morphology in relation to known sources (section 7.9) and this may lead to the construction of theories as to how Bronze Age mining was organized. The lack of specific ore-dressing tools (section 6.2), with the exception of the Great assemblage where they may date to later mining activity, and the continued use of mauls and fragments thereof for ore-dressing at the mines with hard mineral deposits (sections 7.3.2.3 and 7.7.2) suggests that there may have been a lack of division of labour between mining and ore-processing. For Copa Hill, stone hammers and anvils have been shown to be morphologically identical (section 7.3.2.3) which suggests that cobbles were selected primarily for use as hammers and that they continued in use from rock extraction through to ore-dressing. The cobble survey (chapter 8) has demonstrated that there must have been a considerable investment in time finding and transporting cobbles of suitable size, shape and lithology for use as hammers. Although the prehistoric miner was prepared to do this, cobbles of more suitable shape and size for ore-processing were not brought in. The lack of developed processing tools, even of reused hammer fragments, and the lack of evidence for activity areas associated with ore-dressing for recently surveyed and excavated mine sites, such as tool clusters or diagnostic spoil, suggests that mining campaigns extracted only a small quantity of material probably limited to a small number of fire-settings. The stone tool evidence suggests that the extraction procedures did not generate task division. The continued use and reuse of stones and pieces from their breakage, while others were discarded, may suggest that tools stayed in the hands of the same person and that Bronze Age metal mining was an individual rather than a group activity.

The evidence for ore-processing at the hard mineral deposits consists of hammers and fragments thereof whose faces have been used to crush ore 'block-on-block' in a coarse and cursory way. There is no evidence to suggest that finer processing, such as pounding, grinding and washing, carried out in other European Bronze Age mining districts (Gale & Ottaway 1990, 1991), was employed in British mining. It is possible that further processing was carried out at other sites or settlements but whether finely crushed ore was used in the smelting of copper ore in the British Bronze Age is not known. The use of hammers to crush the ore would have been less efficient than employing hollowed and cupped surfaces, such as stone benches and mortars, even with the use of an apron or sheet to catch spilt and flying ore. Although metal is regarded by prehistorians as a prized commodity, the undeveloped form of the mine workings and stone tooling techniques, and the lack of other material remains suggests that the recovery of copper ore was not particularly efficient or well organized.

For sites with soft mineral deposits where the consumption of tools due to breakage was low, the stockpiling as fresh supplies of cobbles at the Great Orme (section 7.2.1.3) and the discarding of considerably modified yet unused cobbles at Alderley Edge (table 6.1) would suggest fresh supplies of tools were brought in for each mining campaign and that little attempt was made to recover tools abandoned from previous workings. At other mine sites in Ireland, large quantities of usable stones have also been reported (O'Brien 1991, 130; Budd pers. comm.). This lends further support to the suggestion that some considerable time elapsed between mining campaigns.

9.2 Stone tool analysis

The analysis of tool form is based, in the most part, on methods employed by geomorphologists and sedimentologists in the study of rock particles. A number of observations and conclusions can be drawn from this study on the suitability of these measurements for the analysis of cobble tool material:

1) Roundness indices are found to be more powerful shape discriminators than axial indices in the comparison of cobble types and sources, for example glacial versus non-glacial cobbles (section 7.2.1.2) and the comparison of tool assemblages and cobble sources (sections 8.3.4 and 8.4.3).

2) Numeric shape measurements are of limited value for assemblages which are highly damaged because too few of them can be related to cobble size (sections 7.3.2.1, 7.4 and 7.5). In these situations, ordinal units for measuring shape and roundness have to be used for which statistical inferences are less powerful.

3) The roundness indices of worked ends (Rmax and Rmin) are found to be closely related to Kuenen's roundness formula (Rk) and the cross-sectional roundness formula (Rxs). Further measurement of the roundness of worked ends will be of little value except where the researcher wishes to examine the effect of roundness on the selection of ends for hammer working for cobbles originating from different types of sediments. In such cases, however, the roundness values for all used and unused ends of the cobble would have to be measured and this would be a very time consuming exercise.

4) Ordinal scales for visual roundness, surface smoothness and shape forms are useful shape and roundness measurements. Although these have in the main been used as descriptive statistics they have demonstrated reliable distinctions between cobble types for the Great Orme material (sections 7.2.1 and 7.2.2).

5) Scratch hardness values are used as a descriptive statistic. While it would be possible to use narrower class units by selecting more comparable materials of known scratch hardness, the variable mineral composition of rocks would make this a difficult statistic to use inferentially.

6) Surface marks and textures are successfully used to distinguish between glacial cobbles, other rounds and ventifacts (sections 7.2.1.2 and 7.6.1.1). Some surface textures are fairly ubiquitous, chink marks and plate scars, while other marks may be strongly associated with specific cobble types without being diagnostic, for example fracture is commonly associated with glacially worked cobbles. If surface marks and textures are to be used as a means of identifying cobble types rather than the selection or avoidance of these in relation to tool

types, then it can be suggested that the presence of bruise marks, chink marks, plate scars and flake scars do not need to be recorded.

7) Macroscopic use-wear is based on form classes ordered by the degree of damage to the stone and measured by the amount of work in ordinal units on scale of zero to three. Although it is a crude form of measurement, because of the lithological variation in the material and the overlap between forms, it is found to be effective in suggesting type subdivisions within end-worked hammers for the Great Orme and Alderley Edge assemblages (sections 7.2.2.1 and 7.6.2.3 respectively). These show poor morphological resolution, however, although they are size correlated.

8) A numerically based measurement of use-wear has been attempted by measuring the depths of hinge terminations to flake scars. These are found to be related to cobble size and unrelated to use-wear types.

9) The use of unmodified and modified hammers is compared using an ordinal scale to measure the amount of work for both ends of two-ended cobbles. This suggests that there are no differences in working between these two hammer forms with the possible exception of the Copa Hill assemblage (section 7.3.2.2).

CHAPTER TEN

Conclusions & Further Work

10.1 Conclusions

A number of methodological and interpretative conclusions can be drawn from this study:

1) For soft mineral deposits, there is evidence for stone hammer specialization. For the Great Orme, differences in hammer size, shape and use-wear are linked to differences in the form of mine workings resulting from variable geological structure.

2) By examining use-wear it is possible to identify other tool materials used in conjunction with stone hammers. It is suggested that bone/wood points were employed at the Great Orme as well as metal tools which may have also been used at other sites.

3) With reference to the two previous conclusions, the study of surface collections of stone tools in themselves does hold some potential in the understanding of mining techniques for a mine site. This potential can only be measured by future work which targets assemblages of relatively complete tools for sites where they can be related to known working forms. Its is anticipated that this area of study will take along time to develop due to the rarity of such situations.

4) On the analysis of stone tools use in relation to available tool sources, it is suggested that Bronze Age mining campaigns were a short-lived, small, group-based activity which extracted only small quantities of copper ore to meet local metal demands.

5) The Bronze Age period lacks developed ore-processing tools and evidence for refined comminution, suggesting ore recovery was not particularly efficient and the local metal industry relatively undeveloped.

6) The fresh supplying of tools as evidenced by stockpiling of cobbles at Great Orme and modified yet unused hammers at Alderley Edge, suggests that considerable time elapsed

between mining campaigns.

7) For the analysis of tool shape, roundness indices are found to be more powerful than axial indices.

8) The division of macroscopic use-wear into form classes and the amount of use into a simple ordinal scale are used successfully to support type subdivisions within end-worked hammers.

10.2 Recommendations for future research

A number of areas requiring further investigation can be identified.

1) Extension of the work in relation to cobble sources in order to assess the time taken to obtain suitable tool material. This could be achieved by timed searches to find suitable cobbles and, mostly in the case of the Alderley Edge material, measuring the time required to modify them.

2) Replication of use-wear marks in order to: i) verify that very soft pound marks result from hammering bone, ii) investigate whether 'notched' ends and striae are produced by hammering metal tools, and iii) verify that polish and polished striae observed for the Alderley Edge hammers are produced by working softer sandstone/marl.

There are a number of further areas of work worthy of investigation at the Great Orme:

3) Assessment of the degree to which subrounded limestone cobbles were utilized as stone tools.

4) Extension of future work to underground contexts on a large scale. With the completion of the underground survey sponsored by CADW, it should now be possible to test the results of this thesis against material uncovered from underground spoil contexts which can be related to specific mine working forms.

5) A measure of the extent of mining on the introduction of metal tools could be obtained by surveying the occurrence of hammers used with metal tools in relation to the ore mineralogy and the position of the mine face.

6) A study of the relationship between cobble lithology and morphology in order to examine the results obtained in section 7.2.2.1.

Further areas of work on the Copa Hill material can also be suggested.

8) The possibility of a bimodal size distribution to the Copa Hill hammers should be investigated by examining the material recovered from more recent excavations.

9) A petrological study needs to be undertaken to verify and assess the scale of use of cobbles derived from Irish Sea till.

APPENDIX

Cobble Survey Data

A1.1 Beach cobble survey, Gogarth Bay, the Great Ormes Head

Sample 1. High tide mark

a axis (mm)	b axis (mm)	c axis (mm)	Dk (mm)	Dxs (mm)	Visual roundness	Weight (kg)	Facial shape	Surface condition
177	115	115	20	15	0.5	2.45	3	-
119	104	80	60	25	0.6	1.75	2	-
105	100	88	50	25	0.6	1.40	2	-
102	89	50	100	10	0.6	0.65	3	-
103	69	47	40	30	0.7	0.50	3	-
94	103	72	10	5	0.3	0.80	2	-
242	172	101	30	10	0.5	4.90	2	-
114	73	49	10	15	0.4	0.45	3	-
152	127	90	30	20	0.6	1.05	2	-
87	68	49	40	5	0.6	0.40	1	-
78	81	72	10	10	0.5	0.65	2	-
116	87	74	50	15	0.5	1.05	3	-
94	90	57	30	15	0.5	0.65	3	-
159	124	91	40	25	0.5	2.45	2	-
98	73	61	40	15	0.6	0.75	2	-
150	110	67	20	15	0.6	1.40	2	-
77	55	34	20	15	0.6	0.30	1	-
82	60	42	20	15	0.7	0.30	2	-
107	81	46	30	10	0.6	0.50	2	-
143	108	65	30	15	0.5	1.20	2	-
114	81	55	40	15	0.6	0.70	2	-
108	76	58	40	20	0.6	0.70	2	-
183	100	98	30	10	0.5	1.90	2	-
108	88	55	20	10	0.4	0.70	3	-
79	71	59	40	20	0.5	0.45	1	-
115	107	41	30	20	0.6	0.85	3	-
113	85	66	30	30	0.6	0.85	3	-
135	110	84	60	25	0.6	1.80	2	-
135	122	65	30	10	0.5	1.10	3	-
182	139	95	20	15	0.6	2.60	2	-
91	55	27	20	10	0.5	0.20	2	-
85	84	36	20	10	0.5	0.30	3	-
173	94	43	20	10	0.5	0.50	3	Snub scars
162	120	59	30	20	0.6	1.70	3	-
95	68	39	20	15	0.5	0.35	3	-
113	107	49	50	10	0.6	0.70	3	-
231	148	39	40	40	0.6	6.50	3	-
120	71	60	20	15	0.5	0.40	3	-
103	65	43	20	20	0.6	0.25	2	-
155	145	52	50	15	0.6	1.50	2	-
111	83	58	20	15	0.5	0.70	3	-
180	139	116	60	20	0.5	3.60	3	-
99	66	65	30	25	0.6	0.60	2	-
79	55	55	30	10	0.6	0.40	2	-
95	63	52	40	25	0.6	0.40	1	-
106	51	50	20	20	0.7	0.30	2	-

a axis (mm)	b axis (mm)	c axis (mm)	Dk (mm)	Dxs (mm)	Visual roundness	Weight (kg)	Facial shape	Surface condition
111	74	78	30	15	0.5	0.80	3	-
187	93	88	30	15	0.5	2.05	2	-
113	68	66	30	25	0.5	0.90	2	-
107	76	39	10	5	0.4	0.50	2	-
137	90	61	30	20	0.6	1.30	2	-
120	85	71	40	25	0.5	1.00	3	-
80	53	53	30	15	0.6	0.30	2	-
120	97	47	20	10	0.5	0.60	2	-
130	81	56	40	20	0.5	0.60	2	-
126	91	62	30	20	0.5	0.80	3	-
116	82	54	50	30	0.7	0.75	2	-
88	51	36	30	10	0.6	0.30	3	-
89	71	43	10	10	0.5	0.30	3	-
145	115	48	40	10	0.6	0.90	3	-
82	61	46	40	25	0.8	0.35	1	-
153	98	69	10	5	0.3	1.10	2	-
101	75	68	30	30	0.6	0.70	1	-
78	53	47	16	20	0.6	0.25	2	-
112	77	57	10	15	0.5	0.75	2	-
95	79	50	30	20	0.5	0.45	3	-
82	75	46	30	10	0.6	0.40	2	-
114	88	75	50	25	0.6	0.80	3	-
119	81	49	40	10	0.6	0.60	3	-
150	123	148	50	25	0.7	1.40	3	-
168	94	90	40	25	0.6	1.45	2	-
141	105	84	40	10	0.5	1.30	3	-
130	93	79	36	25	0.5	1.40	3	-
99	78	33	30	10	0.5	0.30	2	-
140	95	76	30	15	0.5	1.30	3	-
101	75	59	50	10	0.7	0.60	2	-
90	45	42	20	15	0.6	0.20	2	-
97	70	30	36	10	0.7	0.30	2	-
119	110	53	60	20	0.7	0.90	3	-
157	96	67	50	35	0.7	1.50	3	-
107	72	61	16	10	0.5	0.60	2	-
184	171	91	40	25	0.5	3.90	3	-
95	76	56	30	20	0.6	0.60	2	-
205	122	86	40	20	0.5	3.50	3	-
146	102	48	20	5	0.5	0.80	3	-
166	78	60	30	15	0.5	1.20	2	-
111	70	45	40	20	0.7	0.60	1	-
163	106	68	30	25	0.6	1.80	2	-
131	113	51	50	15	0.5	0.80	3	-
120	112	71	30	25	0.5	1.35	3	-
90	54	49	30	10	0.6	0.35	2	-
115	81	113	60	30	0.5	1.60	2	-
130	78	49	30	10	0.5	0.60	3	-
104	91	72	20	15	0.5	0.80	2	-
132	73	72	40	10	0.5	0.80	2	-
89	58	50	30	15	0.5	0.30	1	-
154	92	66	40	15	0.5	1.00	2	-
110	100	51	20	15	0.5	0.65	3	-
130	75	76	30	25	0.6	0.90	3	-
109	99	34	40	20	0.8	0.50	3	-
85	76	48	40	20	0.7	0.55	1	-

a axis (mm)	b axis (mm)	c axis (mm)	Dk (mm)	Dxs (mm)	Visual roundness	Weight (kg)	Facial shape	Surface conidtion
152	67	50	20	20	0.5	0.65	2	-
82	68	38	30	15	0.6	0.25	3	-
80	62	30	30	10	0.7	0.25	2	-
87	57	47	20	10	0.5	0.25	2	-
150	102	52	20	5	0.4	1.00	3	-
128	70	73	40	15	0.5	0.70	3	-
119	45	25	10	5	0.5	0.20	2	-
88	92	44	30	10	0.5	0.50	2	-
100	58	56	20	20	0.6	0.40	1	-
128	85	73	40	10	0.4	1.15	3	-
82	71	34	30	15	0.6	0.30	2	-
72	50	53	20	20	0.5	0.35	3	-
71	40	16	20	5	0.5	0.10	2	-
81	53	28	10	5	0.5	0.10	3	-
76	41	31	10	5	0.5	0.10	2	-
84	65	26	36	10	0.6	0.20	1	-
79	61	44	40	20	0.6	0.20	1	-
72	54	17	20	5	0.4	0.10	2	-
75	70	36	10	15	0.5	0.30	2	-
85	37	24	20	20	0.7	0.20	2	-
86	51	37	20	5	0.4	0.15	2	-
77	80	34	10	15	0.4	0.25	3	-
79	57	40	30	5	0.5	0.25	1	-
75	40	32	16	5	0.5	0.20	3	-
71	51	25	10	10	0.4	0.20	3	-
71	40	22	10	5	0.4	0.10	3	-
81	59	38	20	15	0.5	0.25	3	-
73	58	51	30	5	0.5	0.30	3	-
72	54	34	10	10	0.5	0.20	2	-
182	127	41	30	15	0.5	0.60	2	-
68	70	24	10	5	0.4	0.20	2	-
130	63	44	20	20	0.6	0.45	2	-
202	180	152	70	35	0.5	7.60	3	-
231	118	110	20	15	0.5	3.90	2	-
88	61	38	20	15	0.6	0.40	1	-
75	72	25	20	10	0.6	0.15	2	-
107	65	42	40	20	0.6	0.40	2	-
95	66	51	20	10	0.5	0.30	3	-
185	158	103	70	20	0.6	3.50	3	-
72	57	45	40	15	0.6	0.15	2	-
108	78	54	20	20	0.5	0.65	3	-

Sample 2. Plunge step

a axis	b axis	c axis	Dk	Dxs	Visual roundness	Weight	Facial shape	Surface condition
140	128	99	30	30	0.5	2.90	3	-
180	146	88	50	40	0.6	2.90	3	-
261	206	131	30	35	0.5	9.10	3	-
172	133	105	50	50	0.6	2.50	3	-
110	85	70	30	20	0.5	0.90	2	-
159	140	100	56	30	0.7	3.85	2	-
217	121	80	20	10	0.5	2.45	3	-
143	130	86	20	10	0.5	1.95	3	-
133	80	47	30	15	0.6	0.70	2	-
163	98	90	40	35	0.6	1.95	1	-
220	166	82	40	15	0.5	4.30	1	-
171	125	58	40	15	0.6	1.70	2	-
90	60	39	20	15	0.5	0.25	2	-
226	179	148	80	30	0.5	8.00	3	-
151	120	94	70	50	0.7	2.80	1	-
245	197	171	80	35	0.5	11.20	3	-
123	120	45	20	10	0.5	0.70	1	-
126	79	65	30	15	0.5	0.95	3	-
94	73	50	20	10	0.6	0.60	2	-
170	150	85	60	20	0.6	0.32	2	-
261	186	98	80	50	0.7	6.90	3	Barnacles
229	175	105	30	25	0.5	0.58	2	Barnacles
183	172	76	100	35	0.7	0.30	2	-
123	81	42	40	20	0.6	0.50	1	-
107	66	56	40	30	0.6	0.50	3	-
115	134	67	30	15	0.5	2.40	2	-
145	135	85	70	20	0.5	2.10	3	-
171	139	96	14	25	0.5	3.50	2	Broken
216	168	103	60	20	0.5	3.80	3	-
176	158	108	120	50	0.8	4.10	1	-
147	113	89	20	20	0.5	2.00	3	-
206	125	96	30	15	0.5	2.85	3	-
147	103	87	40	20	0.5	1.85	3	-
139	98	58	70	30	0.7	1.20	2	-
115	93	60	60	30	0.7	0.90	1	-
208	186	154	80	20	0.5	7.80	3	Seaweed
361	221	188	60	30	0.5	15.10	3	Seaweed
203	120	103	40	10	0.5	2.70	2	Broken
183	127	88	20	20	0.5	2.70	2	-
73	70	52	40	15	0.6	0.30	2	-
102	86	43	70	25	0.8	0.70	2	-
85	52	32	30	15	0.6	0.20	2	-
108	103	50	40	15	0.6	0.80	3	-
95	73	36	30	15	0.5	0.40	3	-
146	123	48	36	8	0.5	1.30	2	-
148	72	51	14	20	0.5	0.80	3	-
139	84	59	30	10	0.5	0.90	2	-
139	72	43	30	20	0.6	0.75	2	Barnacles
100	81	55	40	15	0.5	0.80	3	-
76	53	15	20	5	0.6	0.10	2	-
110	56	51	14	10	0.6	0.40	3	-
92	56	29	16	5	0.5	0.20	3	-
104	52	47	10	5	0.5	0.35	2	-

a axis	b axis	c axis	Dk	Dxs	Visual roundness	Weight	Facial shape	Surface condition
87	40	27	30	15	0.7	0.10	1	-
350	238	209	60	30	0.5	20.30	3	Barnacles & seaweed
296	206	165	50	25	0.5	8.60	3	Barnacles
305	213	97	150	30	0.8	8.60	2	Barnacles
239	182	105	40	30	0.5	6.20	3	-
187	104	72	18	45	0.5	1.95	1	Barnacles & seaweed
246	179	113	60	25	0.5	7.50	2	Seaweed
107	101	55	20	10	0.5	0.90	3	-
76	72	40	30	10	0.6	0.30	2	-
95	50	38	14	9	0.5	0.20	2	-
84	48	39	24	20	0.7	0.25	1	-
80	63	30	16	1	0.4	0.15	2	-
75	57	32	12	10	0.7	0.20	1	-
94	45	14	24	5	0.6	0.10	2	-
73	45	33	16	10	0.6	0.15	2	-
73	56	41	16	10	0.5	0.20	3	-
72	60	52	6	2	0.3	0.30	3	Barnacles
77	56	34	12	2	0.3	0.20	3	-
90	56	34	14	10	0.5	0.20	2	-
79	57	26	38	15	0.6	0.15	2	-
80	53	41	30	15	0.7	0.20	1	-
102	95	50	36	25	0.6	0.70	2	-
132	109	38	70	25	0.8	0.90	2	-
70	65	38	30	30	0.6	0.30	1	-
98	79	48	30	20	0.6	0.50	2	-
77	55	40	20	20	0.6	0.20	3	-

Sample 3. Backshore

a axis	b axis	c axis	Dk	Dxs	Visual roundness	Weight	Facial shape	Surface condition
101	70	52	20	10	0.5	0.35	3	-
124	83	57	30	20	0.5	0.90	2	-
151	145	73	20	5	0.4	2.25	3	-
100	77	64	30	20	0.6	0.70	2	-
85	83	59	10	10	0.5	0.50	2	-
125	78	70	20	20	0.6	1.05	2	-
77	58	47	30	10	0.6	0.30	1	-
112	64	62	16	10	0.5	0.50	2	-
172	140	80	16	5	0.4	2.00	3	Broken
235	172	141	40	5	0.5	5.30	2	-
202	193	120	20	5	0.4	5.05	3	-
287	208	176	20	5	0.4	12.80	3	-
98	86	38	10	5	0.5	0.30	3	Broken
91	81	58	30	20	0.6	0.65	2	-
138	115	68	20	10	0.5	1.10	2	Broken
162	111	85	20	5	0.4	1.40	3	Broken
117	96	57	10	5	0.4	0.75	3	Broken
114	102	49	30	10	0.5	0.70	3	-
175	124	95	20	5	0.5	2.10	2	Broken
83	75	40	56	25	0.7	0.30	1	-
171	122	101	20	15	0.5	3.10	2	-
99	73	84	10	10	0.5	0.90	3	-
123	122	63	40	15	0.5	1.15	2	-
117	83	76	30	10	0.5	0.85	3	-
249	176	99	50	15	0.5	5.35	2	-
109	100	67	20	15	0.5	0.90	2	-
97	56	54	20	10	0.5	0.30	2	-
108	70	78	30	15	0.5	0.70	2	-
231	110	90	16	5	0.5	2.10	2	-
105	84	55	30	17	0.6	0.60	3	-
106	74	50	10	15	0.5	0.60	2	-
265	179	75	30	5	0.4	4.55	3	-
152	123	53	50	15	0.5	1.55	2	-
95	60	33	16	10	0.5	0.30	2	-
113	86	49	20	5	0.5	0.50	3	-
123	91	79	10	5	0.3	0.90	3	-
98	80	53	4	5	0.2	0.40	3	-
157	123	85	6	15	0.4	1.90	3	-
110	59	45	20	10	0.6	0.40	2	-
83	58	21	10	5	0.4	0.10	2	-
95	45	41	6	2	0.4	0.20	2	-
75	46	26	20	15	0.6	0.10	3	-
81	60	43	16	10	0.6	0.30	2	-
90	45	27	20	5	0.6	0.10	3	-
201	196	110	20	2	0.4	5.15	3	Broken
131	54	57	30	5	0.6	0.50	1	-
80	48	41	16	10	0.5	0.10	3	-
88	69	40	20	10	0.5	0.30	2	-
145	115	47	30	15	0.5	0.90	3	-
284	179	176	40	10	0.5	12.00	2	-
236	194	123	30	10	0.5	6.40	2	-
328	192	168	20	15	0.4	10.00	3	-
293	225	135	40	35	0.6	12.30	3	-

a axis	b axis	c axis	Dk	Dxs	Visual roundness	Weight	Facial shape	Surface condition
102	83	49	40	15	0.5	0.60	3	-
108	75	57	10	5	0.4	0.60	3	-
129	114	72	36	25	0.5	1.40	3	-
137	108	126	38	7	0.5	0.50	2	-
193	139	111	24	15	0.5	3.50	3	Broken
188	135	39	12	5	0.4	1.10	2	-
261	256	68	12	10	0.5	5.20	3	Broken
190	170	106	40	15	0.5	5.20	3	-
131	101	59	38	20	0.5	1.00	3	-
121	75	42	10	10	0.4	0.40	2	-
106	81	56	8	3	0.3	0.40	3	-
86	66	33	2	1	0.2	0.15	2	-
79	44	38	30	15	0.6	0.20	2	-
88	70	62	10	10	0.5	0.40	3	Broken
92	67	58	6	3	0.3	0.35	3	-
85	61	45	6	4	0.3	0.30	3	-
83	55	33	-	10	0.5	0.20	2	Broken

A1.2 Cwmystwyth

Sample 1. Hillslope wash, Lanfawr

1) Fine-grained rocks

a axis (mm)	b axis (mm)	c axis (mm)	Dk (mm)	Dxs (mm)	Visual roundness	Weight (kg)	Facial shape	Striae	Surface condition
175	165	40	10	5	0.4	1.60	3	0	-
188	128	60	16	5	0.5	1.80	3	1	-
110	83	57	16	5	0.5	0.60	3	2	-
114	77	60	2	5	0.2	0.60	2	0	-
202	78	41	4	2	0.3	0.50	3	1	-
88	87	32	6	2	0.4	0.20	3	0	-
158	87	30	10	1	0.3	0.55	2	3	-
119	87	45	4	2	0.3	0.60	3	0	-
98	78	42	2	1	0.2	0.25	3	0	-
99	67	47	6	25	0.3	0.45	2	1	-
95	74	36	6	1	0.2	0.30	2	0	-
113	70	37	6	3	0.3	0.30	2	1	-
122	55	38	2	5	0.3	0.35	2	0	-
85	77	32	14	5	0.4	0.30	2	3	-
122	72	49	6	1	0.4	0.40	3	1	Broken
152	107	56	6	10	0.4	1.10	2	0	-
197	149	100	30	10	0.5	3.70	2	2	Snub scar
134	81	36	6	3	0.4	0.45	2	3	-
120	93	35	4	1	0.2	0.50	3	0	Broken
113	64	48	2	2	0.3	0.40	2	1	-
124	88	39	4	5	0.3	0.35	2	2	-
148	91	35	2	1	0.3	0.40	2	0	-
134	102	34	4	1	0.2	0.50	3	1	-
168	96	75	14	5	0.4	1.30	3	0	Snub scar
159	88	30	2	1	0.2	0.40	2	0	-
129	83	48	8	3	0.3	0.80	2	0	-
172	103	40	4	5	0.3	0.70	2	0	-
144	108	45	2	1	0.2	0.70	2	0	-
164	144	27	4	3	0.3	0.60	2	0	-
152	115	26	2	1	0.3	0.70	2	0	Broken
136	85	57	4	1	0.3	0.70	2	1	-
111	65	40	4	4	0.3	0.40	2	0	-
142	61	42	2	1	0.2	0.50	3	0	-
125	76	38	2	2	0.3	0.50	2	2	-
126	58	30	6	1	0.2	0.30	2	0	-
110	61	45	4	1	0.3	0.40	3	1	-
97	76	48	8	1	0.4	0.50	2	1	-
148	88	44	4	2	0.3	0.60	2	2	-
176	104	31	6	5	0.3	0.60	2	1	-
125	73	34	2	1	0.3	0.35	3	0	-
97	63	38	8	3	0.3	0.30	2	1	-
105	48	45	8	3	0.4	0.30	3	0	-
96	68	34	4	2	0.3	0.20	2	2	-
98	70	25	4	1	0.2	0.30	3	1	-
115	68	34	6	2	0.3	0.20	2	2	-
126	67	32	4	1	0.2	0.30	3	1	-
98	85	20	2	1	0.1	0.20	2	1	-
108	80	23	2	1	0.2	0.30	2	1	-

a axis (mm)	b axis (mm)	c axis (mm)	Dk (mm)	Dxs (mm)	Visual roundness	Weight (kg)	Facial shape	Striae	Surface condition
123	64	41	2	1	0.3	0.50	2	2	-
197	123	90	8	15	0.4	2.60	3	3	-
108	78	30	2	3	0.3	0.30	2	1	-
129	86	31	4	2	0.3	0.30	2	2	-
133	96	40	8	3	0.3	0.50	2	0	-
165	81	38	4	1	0.3	0.65	2	0	-
148	67	31	4	1	0.2	0.35	3	0	-
177	132	52	6	3	0.3	2.00	2	3	-
186	97	55	6	1	0.2	1.10	3	0	-
126	88	56	4	1	0.2	0.40	3	0	-
116	71	45	6	2	0.3	0.25	3	0	-
146	75	38	4	1	0.2	0.30	2	2	-
156	110	31	4	1	0.3	0.50	2	0	-
116	62	44	4	1	0.2	0.30	3	0	-
132	73	29	4	1	0.1	0.30	3	1	-

Medium-grained rocks

a axis (mm)	b axis (mm)	c axis (mm)	Dk (mm)	Dxs (mm)	Visual roundness	Weight (kg)	Facial shape	Striae	Surface condition
180	126	73	16	5	0.5	1.70	2	3	-
180	78	35	2	1	0.1	0.40	3	0	-
123	83	49	6	2	0.4	0.50	3	1	-
133	105	91	10	1	0.4	1.40	2	2	Broken
117	75	54	6	10	0.4	0.50	2	2	Snub scar
364	150	55	4	1	0.4	2.10	3	1	Broken
139	102	77	10	2	0.3	0.35	3	1	Broken & snub scar
117	75	28	6	5	0.4	0.25	3	0	-
203	172	86	20	10	0.5	3.40	2	1	-
156	127	113	6	10	0.4	2.50	2	1	Snub scar
117	121	59	2	1	0.1	0.90	2	0	-
176	118	28	6	1	0.3	0.80	3	0	Broken
198	166	53	8	2	0.4	1.60	2	3	-
198	162	59	4	1	0.2	1.70	2	2	Broken
99	98	70	8	5	0.4	*	2	2	-
112	93	51	4	1	0.3	0.60	3	2	-
139	110	57	10	1	0.3	1.15	3	0	-
153	60	57	8	5	0.4	0.70	2	1	-
83	62	47	6	2	0.4	0.30	2	1	-
160	60	30	2	1	0.1	0.10	3	0	-
125	91	47	8	1	0.4	0.65	2	2	-
95	92	37	6	1	0.2	0.30	2	1	-
157	63	32	2	1	0.1	0.30	3	0	-
138	96	51	4	1	0.2	0.60	3	0	-
205	47	32	4	1	0.1	0.25	2	1	-
184	57	23	4	2	0.1	0.20	3	0	-

Coarse-grained rocks

a axis (mm)	b axis (mm)	c axis (mm)	Dk (mm)	Dxs (mm)	Visual roundness	Weight (kg)	Facial shape	Striae	Surface condition
168	88	51	2	1	0.5	0.80	3	3	Broken
239	148	52	10	1	0.4	2.40	3	1	Broken
305	182	110	16	20	0.5	6.50	3	0	-
187	140	65	24	10	0.5	1.70	2	1	-
195	132	86	6	10	0.5	2.40	2	2	Snub scar
95	68	62	14	2	0.4	0.35	3	0	Snub scar
193	105	93	18	15	0.5	2.35	2	3	-
120	78	51	8	5	0.4	0.55	3	0	Snub scar
122	82	43	4	5	0.4	0.45	3	0	Snub scar
184	102	67	4	5	0.4	1.50	3	0	-
188	90	50	6	5	0.4	1.00	2	3	-
238	156	75	30	10	0.5	3.50	2	2	Broken
161	94	93	18	30	0.5	1.80	2	2	-
172	74	49	6	10	0.4	0.70	2	0	-
130	106	64	4	1	0.3	0.80	3	1	-
158	97	54	6	2	0.3	1.05	3	0	-
123	62	44	12	15	0.5	0.60	2	0	-
117	74	45	10	5	0.4	0.60	3	0	-
120	95	55	12	5	0.4	0.70	2	1	-
135	77	65	10	1	0.3	0.55	3	0	-
107	84	63	4	1	0.3	0.60	2	1	-
171	81	28	2	1	0.1	0.20	3	0	-
88	74	37	14	2	0.4	0.30	3	1	Broken
224	161	78	6	1	0.3	2.50	3	0	-
196	175	78	16	1	0.4	2.65	3	1	-
129	99	51	16	8	0.4	0.70	2	1	Snub scar
170	126	49	2	1	0.1	0.70	3	0	-
115	81	52	12	5	0.3	0.50	3	2	-
190	93	50	8	10	0.4	0.80	2	2	-
162	115	39	6	1	0.2	0.60	3	2	-
195	94	91	6	5	0.4	1.45	2	3	-

Sample 2. Stream gravel, valley-side tributary, Lanfawr.

1) Fine -grained rocks

a axis (mm)	b axis (mm)	c axis (mm)	Dk (mm)	Dxs (mm)	Visual roundness	Weight (kg)	Facial shape	Striae	Surface condition
182	158	35	4	1	0.3	1.40	2	0	-
107	102	62	8	2	0.3	0.95	3	0	-
86	82	36	4	5	0.3	0.40	3	0	-
205	139	62	12	5	0.3	2.65	2	0	-
156	87	44	14	3	0.4	0.60	2	0	-
113	118	51	4	2	0.2	1.00	2	0	-
273	186	70	14	10	0.3	4.40	2	0	-
104	87	39	12	3	0.2	0.55	2	0	-
129	90	33	12	1	0.3	0.50	2	0	-
181	91	22	4	2	0.2	0.40	2	0	-
114	91	30	6	2	0.3	0.50	2	0	-
150	110	33	8	4	0.3	0.80	2	0	-
127	99	49	10	3	0.3	0.85	2	0	-

2) Medium-grained rocks

a axis (mm)	b axis (mm)	c axis (mm)	Dk (mm)	Dxs (mm)	Visual roundness	Weight (kg)	Facial shape	Striae	Surface condition
125	118	58	14	10	0.4	1.00	3	2	-
182	135	41	14	5	0.4	1.50	2	0	-
117	80	40	16	2	0.4	0.40	3	0	-
156	126	74	30	15	0.4	1.55	3	0	-
239	125	59	10	5	0.4	2.25	3	0	-
115	95	54	20	5	0.4	0.80	3	0	-
148	100	63	20	5	0.4	1.05	3	0	-
144	107	92	30	5	0.4	2.05	3	2	-
114	76	40	20	5	0.4	0.40	3	1	-
199	94	25	20	3	0.4	0.80	2	0	-
126	125	65	10	5	0.4	1.30	2	2	-
208	119	67	16	5	0.5	2.20	3	0	-
152	94	65	14	15	0.4	1.30	3	0	-
140	77	47	8	5	0.4	0.55	3	2	-
181	90	50	4	2	0.3	1.10	2	1	-
274	202	64	40	7	0.4	3.90	2	0	-
132	74	57	6	2	0.3	0.70	2	0	-
117	116	70	18	5	0.4	1.10	2	1	-
97	86	39	36	20	0.6	0.40	2	0	-
236	143	30	10	2	0.1	0.80	2	0	-
157	84	33	8	1	0.2	0.35	2	0	Broken
126	95	64	10	2	0.3	0.90	3	0	-

3) Coarse-grained rocks

a axis (mm)	b axis (mm)	c axis (mm)	Dk (mm)	Dxs (mm)	Visual roundness	Weight (kg)	Facial shape	Striae	Surface condition
156	85	58	40	10	0.5	1.00	3	0	-
170	164	61	16	10	0.4	2.30	2	1	-
160	125	71	16	10	0.4	2.10	2	2	-
104	86	71	20	8	0.4	0.60	3	2	-
101	61	51	16	10	0.4	0.40	3	0	-
171	155	57	30	15	0.5	2.30	2	0	-
257	124	60	20	10	0.4	1.70	2	0	-
103	78	42	30	10	0.4	0.40	2	0	-
250	152	77	20	20	0.5	3.50	2	2	-
114	113	62	10	10	0.4	1.10	2	1	-
174	127	35	14	10	0.4	1.05	2	2	-
146	95	73	40	20	0.5	1.30	3	2	-
116	83	53	18	8	0.4	0.55	3	2	-
102	94	36	14	10	0.4	0.45	3	3	-
103	72	39	12	10	0.4	0.40	2	2	-
144	76	56	16	8	0.4	0.60	2	2	-
159	99	35	30	8	0.5	0.60	3	0	-
215	133	82	30	15	0.5	3.30	2	0	-
176	126	69	14	8	0.4	1.80	2	3	-
129	92	75	40	10	0.5	1.10	2	0	-
152	149	56	18	10	0.3	1.40	3	0	-
219	147	84	30	20	0.5	3.50	3	2	-
138	86	68	14	10	0.4	0.60	2	0	-
167	100	43	14	10	0.4	1.10	2	1	-
212	105	71	18	3	0.4	1.60	2	0	-
125	84	35	30	10	0.5	0.40	2	0	-
112	73	39	20	3	0.4	0.40	2	2	-
161	135	63	20	15	0.4	1.90	3	1	-
212	169	117	10	10	0.4	4.10	3	0	-

Sample 3. Stream gravel, River Ystwyth

1) Fine-grained rocks

a axis (mm)	b axis (mm)	c axis (mm)	Dk (mm)	Dxs (mm)	Visual roundness	Weight (kg)	Facial shape	Surface condition
197	94	49	20	4	0.3	0.90	3	-
138	126	67	10	10	0.4	1.30	2	-
135	98	41	16	5	0.3	0.90	2	-
220	99	74	50	15	0.6	2.50	2	-
141	124	38	14	10	0.5	0.70	2	-
185	72	46	18	5	0.4	0.70	2	-
116	84	40	18	10	0.5	0.50	3	-
127	87	21	20	10	0.5	0.50	2	-
214	201	80	30	15	0.5	4.00	3	-
275	192	99	40	15	0.4	5.90	2	-
181	158	71	50	15	0.5	2.55	3	-
187	158	31	10	5	0.3	1.00	2	-
90	75	50	16	10	0.5	0.55	2	-
195	155	108	30	10	0.5	4.20	3	-

2) Medium-grained rocks

a axis (mm)	b axis (mm)	c axis (mm)	Dk (mm)	Dxs (mm)	Visual roundness	Weight (kg)	Facial shape	Surface condition
100	91	71	60	45	0.7	1.00	1	-
110	87	75	30	15	0.4	0.90	3	-
116	71	41	50	20	0.7	0.50	1	-
145	142	45	60	25	0.6	1.50	3	-
148	68	33	30	5	0.6	0.50	2	-
172	138	58	80	15	0.5	1.65	2	-
176	111	89	60	25	0.6	2.30	3	-
184	113	68	30	20	0.6	1.80	3	-
186	119	76	40	20	0.5	1.50	2	-
187	103	65	50	25	0.7	1.60	2	-
190	122	64	40	15	0.7	2.40	2	-
205	167	76	100	35	0.6	*	2	-
205	197	45	4	2	0.5	2.25	3	Broken
213	126	125	50	15	0.5	3.75	3	-
226	101	71	40	10	0.5	1.60	3	-
254	150	98	20	60	0.5	4.10	1	Broken
314	228	122	60	20	0.5	10.40	3	Broken
319	153	73	36	20	0.5	4.40	2	-
164	134	53	60	10	0.5	1.70	3	-
204	107	54	16	10	0.5	1.50	3	-

3) **Coarse-grained rocks**

a axis (mm)	b axis (mm)	c axis (mm)	Dk (mm)	Dxs (mm)	Visual roundness	Weight (kg)	Facial shape	Surface condition
94	91	85	60	20	0.6	0.40	3	-
98	75	28	50	8	0.7	0.30	2	-
110	85	67	40	45	0.6	1.00	1	-
111	83	52	20	7	0.5	0.50	3	-
118	98	63	70	30	0.7	0.90	1	-
127	107	43	40	10	0.5	0.75	3	-
129	93	35	60	20	0.6	0.70	3	-
130	91	28	30	20	0.6	0.40	2	-
131	100	28	70	15	0.7	0.50	2	-
135	85	63	70	40	0.7	1.00	1	-
135	123	50	1	5	0.5	1.20	2	-
141	103	82	44	20	0.6	1.30	1	-
143	108	53	70	20	0.7	1.00	1	-
144	91	82	60	35	0.7	1.35	1	-
144	102	85	30	30	0.5	1.40	3	-
145	90	58	36	20	0.6	1.00	2	-
147	86	65	70	10	0.6	0.80	2	-
154	115	71	50	35	0.6	1.45	1	-
154	135	17	14	5	0.4	0.50	2	-
155	68	43	40	15	0.6	0.50	1	-
163	138	38	20	5	0.5	1.00	2	-
164	130	50	40	15	0.6	1.25	2	-
168	116	40	30	10	0.5	0.90	2	-
169	141	38	40	10	0.6	1.05	2	-
170	125	37	90	15	0.7	1.10	2	-
172	114	55	70	25	0.7	1.50	2	-
176	162	73	100	25	0.7	2.70	3	-
178	162	121	100	35	0.5	4.00	3	-
179	106	72	50	20	0.6	1.80	3	-
181	140	83	120	25	0.7	2.70	1	-
181	168	73	70	20	0.5	2.70	3	-
184	105	44	30	5	0.4	0.90	2	-
185	87	60	36	15	0.5	1.40	3	-
186	115	65	60	40	0.7	2.30	2	-
186	172	73	70	30	0.6	3.30	1	-
187	155	81	90	25	0.7	3.10	1	-
190	130	77	70	60	0.7	2.80	2	-
194	104	98	60	30	0.6	2.70	2	-
196	95	52	70	25	0.7	1.40	1	-
197	129	86	70	40	0.7	4.00	2	-
202	154	51	50	15	0.6	2.30	2	-
205	118	78	50	25	0.6	2.40	2	-
206	139	103	100	45	0.7	3.85	3	-
210	136	70	40	20	0.6	2.00	1	-
210	175	47	10	5	0.4	2.35	2	Broken
212	81	59	50	20	0.7	1.35	2	-
215	145	80	100	30	0.7	3.25	1	-
217	130	50	60	10	0.5	1.65	2	-
217	168	66	70	15	0.5	2.70	3	-
226	190	76	90	20	0.7	4.60	1	-
227	116	68	90	10	0.6	1.90	2	-
230	113	63	30	15	0.5	1.80	2	-
234	98	61	50	25	0.7	1.80	2	-

a axis (mm)	b axis (mm)	c axis (mm)	Dk (mm)	Dxs (mm)	Visual roundness	Weight (kg)	Facial shape	Surface condition
235	113	83	50	30	0.6	3.40	2	-
238	136	40	70	10	0.5	1.60	2	-
240	118	89	50	20	0.5	2.40	2	-
240	210	113	130	20	0.6	7.00	3	-
245	140	100	120	30	0.7	4.30	3	-
249	210	70	70	20	0.6	4.80	3	-
251	134	73	70	15	0.6	3.20	2	-
257	147	94	110	60	0.7	5.00	1	-
264	183	65	50	20	0.5	4.10	3	-
281	135	75	70	35	0.6	3.70	2	-
288	155	59	90	15	0.5	3.60	3	-
289	188	51	70	15	0.5	2.90	2	-
303	201	89	80.	20	0.5	6.70	2	-
340	160	152	20	15	0.7	6.60	2	-
372	113	66	80	20	0.7	4.20	2	-
181	115	70	12	15	0.5	2.10	2	-

Notes

1) Facial shapes are coded '1' for convex, '2' for flat, and '3' for concave.

2) Glacial striae are coded according to their clarity: '1' for weak, '2' for clear, and '3' for strong.

3) Missing values are coded as an asterisk.

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Glossary

Chemical Formulas of Mineral Species Cited

Arsenopyrite	$FeAsS$
Azurite	$Cu_3(CO_3)_2(OH)_2$
Brochantite	$Cu_4(SO_4)(OH)_6$
Cerargyrite	$AgCl$
Cerussite	$PbCO_3$
Chalcocite	Cu_2S
Chalcopyrite	$CuFeS_2$
Chrysocolla	$Cu_2H_2Si_2O_5(OH)_4$
Clinoclase	$Cu_3AsO_4(OH)_3$
Covelline	CuS
Cuprite	Cu_2O
Digenite	Cu_9S_5
Djurleite	$Cu_{31}S_{16}$
Enargite	Cu_3AsS_4
Erythrite	$Co_3(AsO_4)_2$
Galena	PbS
Geothite	$FeO.OH$
Limonite	A generic term for mixed oxides or hydroxides of iron.
Linnaeite	Co_3S_4
Malachite	$Cu_2CO_3(OH)_2$
Olivenite	Cu_2As_4OH
Posnjakite	$Cu_4(SO_4)(OH)_6.H_2O$
Pyrite	FeS_2
Schulenbergite	$(CuZn)_9(SO_4CO_3)(OH)_{10}.3H_2O$
Smithsonite	$ZnCO_3$
Sphalerite	ZnS
Tenorite	CuO